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**SPEECH COMMUNICATION WITH FLAT-ATTENUATION  
HEARING PROTECTORS**

**FINAL REPORT**

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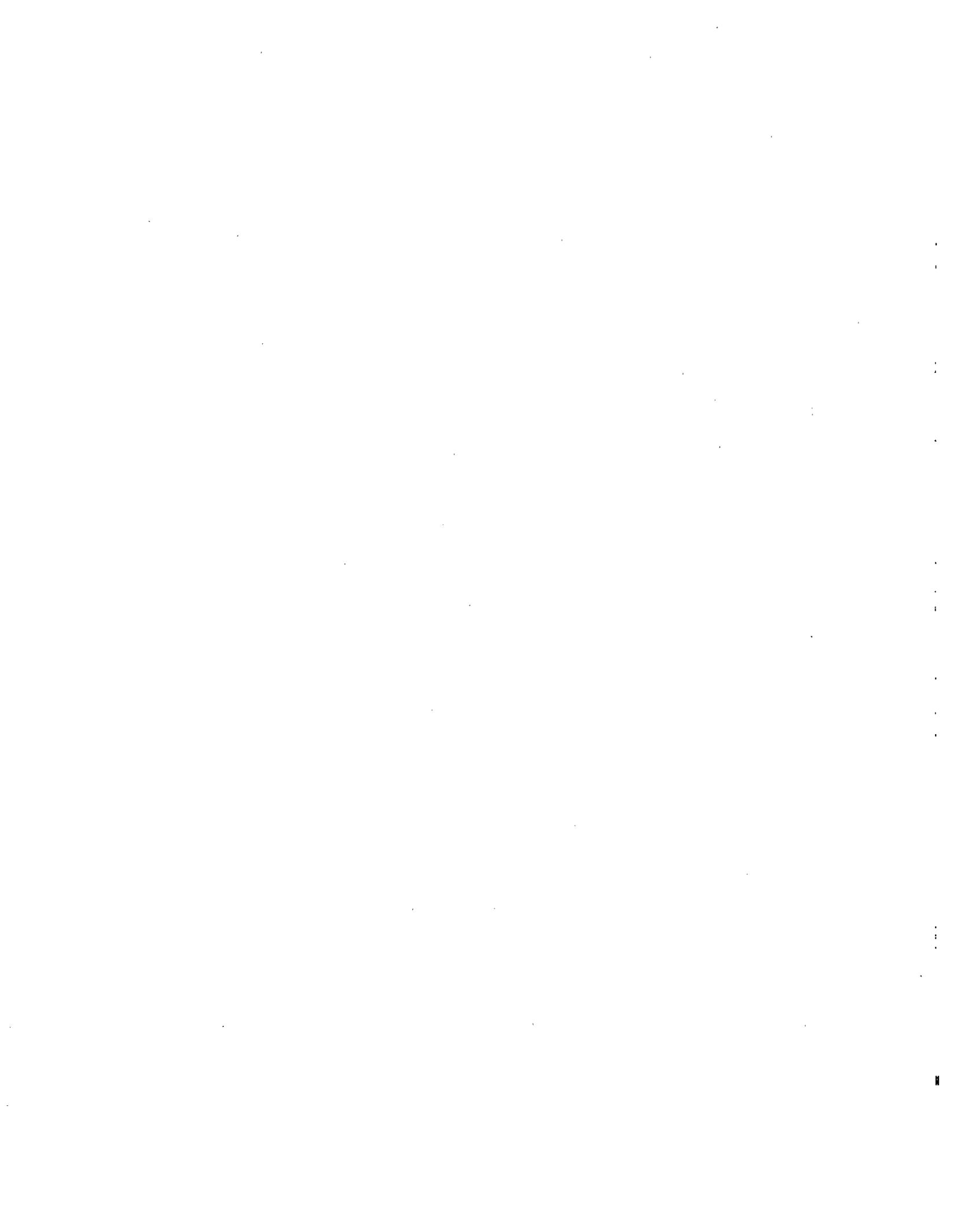
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## 1. LIST OF ABBREVIATIONS

ANOVA	Analysis of variance
ANSI	American National Standards Institute
ASHA	American Speech, Language, and Hearing Association
ATR	audiometric test room
BFO	beat frequency oscillator
CD	compact disk
DSFR	diffuse sound field room
EAR	E.A.R Division of Cabot Co.
ER	Etymotic Research Inc.
HI	hearing-impaired
HL	hearing level
HPD	hearing protection device
LVR	laryngeal voice recording
NH	normal-hearing
No-HPD	no-hearing-protection-device (condition)
NU-6	Northwestern University Auditory Test No. 6
REAT	real ear attenuation at the threshold (test)
RWIN	real-world industrial noise
SBG	simulated battleship game (test)
SCI	speech communication index
SD	standard deviation
SIN	simulated industrial noise
SIR	speech intelligibility rating (test)
SLA	speech level adjustment (test)
SNR	signal-to-noise ratio
SPARE	sound pressure attenuation in the real ear (test)
SPL	sound pressure level
SRT	speech recognition threshold
VET	vocal effort test (test)
WRN	wideband random noise
WRS	word recognition score (test)

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- Table 5.** Mean (M, %) and standard deviation (SD, %) values for word recognition scores (WRS) obtained in this study by NH and HI subjects for various listening conditions.
- Table 6.** Mean (M, %) and standard deviation (SD, %) values for speech intelligibility rating (SIR). The data are listed separately for NH and HI subjects and for various listening conditions.
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#### 4. ABSTRACT

The most common way to reduce noise exposure in the workplace is to wear hearing protection devices (HPDs). The negative effect of wearing HPDs is attenuation of both unwanted-noise and wanted signals. This negative aspect of HPDs is amplified by the fact that a typical HPD attenuates high-frequency sounds (speech, warning signals) more than low-frequency sounds (many industrial noises). The common practice of selecting a HPDs that provides maximum noise attenuation, leads therefore, to overprotecting the wearer and preventing him from hearing high frequency warning signals, sudden changes in machine noise, speech messages, and other important acoustics signals.

Flat-attenuation HPDs are devices that provide frequency-independent noise attenuation. Such devices may eliminate overprotection of the HPD user at high frequencies and, thus, facilitate improved speech communication. However, adequate protection against existing noise levels should not be sacrificed for maximized speech communication. Thus, the proposed study was designed to evaluate the relationship between noise attenuation and speech communication effectiveness resulting from wearing flat-attenuation HPDs in several noisy environments. Various physical and perceptual measures were compared to assess the amount of noise attenuation provided by the protectors as well as the effectiveness of speech communication between workers wearing the protectors. The following measures were directly obtained or calculated in the study: (1) real ear attenuation at the threshold, (2) sound pressure reduction in the ear canal, (3) word recognition score, (4) speech intelligibility rating, (5) battleship game communication, (6) optimum speech level adjustment, and (7) vocal effort in noise. The main findings of the study are listed in Chapter 5: Significant Findings.

#### 5. SIGNIFICANT FINDINGS

The four most important findings of this study are: (1) hearing protector devices (HPDs) negatively affect speech communication in noise under the conditions investigated, (2) noise attenuation and speech communication do not significantly differ among the earplugs compared in this study when all the earplugs were inserted using the informed-user fitting protocol, (3) both speech perception and speech production are affected by HPDs, and (4) the Simulated Battleship Game (SBG) protocol has the potential to be developed into a standardized test for assessing speech communication under various listening conditions.

#### 6. USEFULNESS OF FINDINGS

The findings of the present study emphasize the importance of the quality of earplug insertion on the ability to attenuate noise and on the effectiveness of speech communication in noise. The *informed-user fit*, and even to a greater degree the *user*

*fit*, compromise laboratory measured effectiveness of high-attenuation earplugs but may have a negligible effect on noise attenuation by the earplugs with controlled acoustic leakage. It is useful to know that the effectiveness of the user-fitted flat attenuation earplugs ER-15 and ER-20 is comparable to that of the user-fitted Ultrafit earplug.

It is also important to realize that in typical industrial conditions HPDs tend to compromise speech communication in noise. This effect should always be taken into consideration during HPD dispensing and fitting. The Simulated Battleship Game (SBG) strategy used in this study seems to be a sensitive measure of speech communication in noise between HPD users. However, further studies are needed to develop SBG into standardized test procedure.

## 7. INTRODUCTION

Industrial noise exposure is a major occupational health hazard. The most common way to reduce noise levels in the workplace is to have employees wear hearing protection devices (HPDs). Most HPDs attenuate high-frequency sounds more than low frequency sounds thereby altering speech and environmental signals to a greater degree than low-frequency industrial noises. In addition, employers often select HPDs which provide the most attenuation. Unfortunately, this practice will often overprotect the employee. Consequently, employees will often disable the HPDs or not wear the HPD to enhance speech communication in the workplace. This practice increases the risks of hearing loss and the number of potential hearing loss compensation claims.

A flat attenuation HPD may enhance speech communication without providing overprotection to the HPD user. However, no generally accepted HPD-oriented tests for assessing the adequacy for speech communication in noise exist. The proposed study was designed to evaluate the effectiveness of flat attenuation HPDs in a simulated work environment and to develop a HPD-oriented speech communication measure for the purpose of assessing speech communication effectiveness between HPD wearers. Several objective and perceptual measures were compared to assess the amount of noise attenuation by the protectors (Experiments 1 and 2) as well as the effectiveness of speech understanding and speech communication between workers wearing hearing protectors (Experiments 3 through 7).

## 8. BACKGROUND

Industrial and environmental noises are detrimental to human life in many ways. It is well known that continued exposure to high levels of noise is a major health hazard and a source of the characteristic hearing loss known as noise-induced hearing loss (NIHL). In fact, industrial noise has been recognized as a major occupational health hazard affecting 20 million Americans on a daily basis (ASHA, 1990). Approximately 9 million Americans are exposed to daily noise levels exceeding 85 dBA (EPA, 1981).

People who have to work in noisy environments must protect their hearing. The most common way of reducing the effects of high intensity noise on the auditory system is to wear hearing protection devices (HPDs) (Berger, 1988). The noise attenuation provided by a HPD is physically defined as the difference between the sound pressure levels measured inside and outside the hearing protection device.

Selection of a suitable HPD at a workplace is typically determined by the amount of noise attenuation provided by the HPD. Many employers select HPDs that provide the highest attenuation, making the assumption that the most attenuation is the best. Unfortunately, this practice leads to overprotecting the employee who may not hear warning signals, changes in machine noise, and speech communication from other employees. The greater the per-octave attenuation slope of the HPD the greater is the loss of speech signal audibility (Lazarus, 1986). Consequently, employees will often disable the HPDs or not wear them at all to facilitate speech communication on the job. The ultimate results of such strategy is the increased risk of hearing damage and potential for hearing loss compensation claims.

In fact, the most frequent complaint associated with wearing HPDs is that they reduce the ability to understand speech and to hear warning signals in the workplace (Lindeman, 1976; Wilkins and Martin, 1982; Abel et al., 1982). These communication difficulties arise from the fact that HPDs attenuate both unwanted (noise) and wanted (speech, warning signals) sounds. In addition, a typical HPD attenuates the high-frequency sounds more than the low-frequency sounds thereby reducing the energy that contributes to speech intelligibility more than the energy of the masking noise. The problems with speech perception with HPDs become even more pronounced for hearing-impaired workers who typically exhibit high frequency hearing loss (Lindeman, 1976; Chung and Gannon, 1979; Abel et al., 1982; Bauman and Marston, 1986). The complaints about unsatisfactory speech recognition associated with wearing HPDs are in contrast with results of some studies on the effects of HPDs on speech communication. According to these studies speech-recognition performance is either not affected (Pollack, 1957; Rink, 1979) or enhanced with the use of HPDs in noise levels above 80 to 90 dBA (Kryter, 1946; Michael, 1965; Williams, Forstall, and Parsons, 1971; Lindeman, 1976; Chung and Gannon, 1979; Berger, 1982). However, the above observations have been made in situations when only the listener was wearing HPDs and for listeners with normal hearing (Kryter, 1946; Lindeman, 1976; Chung and Gannon, 1979; Abel et al., 1982). According to Howell and Martin (1975), speech communication deteriorates when the talker is wearing HPDs because spoken messages are reduced both in level and quality. The negative effect of HPDs on the talker's speech levels is greater for earplug- than for earmuff-type HPDs. In addition, reported speech enhancement appears to decrease at negative speech-to-noise ratios and for HPDs worn in low noise levels. Moreover, even if HPDs slightly enhance speech communication in certain situations, in practice the total subjective effect may be still one of a degradation of communication by HPDs (Acton, 1977). Nevertheless, it is generally assumed HPDs provide improved listening conditions for normally hearing users working in noise levels above 80 to 90 dBA (Suter, 1989). The theory behind this improvement is that masking effect of noise increases more than proportionally with increasing noise level. Reduction of both speech and noise levels by the same amount

actually causes some release from masking. Too much reduction may however cause that certain speech sound will fall below the level of audibility. Hearing protection may also decrease the vocal output of the talker and cause additional speech communication difficulties. According to some reports, the poorest performance on speech communication task occurs when both the talker and the listener wear HPDs (see, for example, Hoermann et al., 1984).

Hearing protectors do not affect only the level and quality of signals but also reduce the wearer's ability to localize sound sources. Noble (1981) reported that earmuffs considerably degrade response accuracy in the horizontal plane and virtually destroy it in the vertical plane. Earplugs are much less distractive than earmuffs because they do not eliminate pinna cues that are important in both horizontal and vertical plane (Fisher and Freeman, 1968; Suter, 1989). Earplugs do not usually produce many left-right errors but affect front-back localization with the wearers favoring the back position (Noble and Russell, 1972; Noble, Murray, and Waugh, 1990).

Audibility of speech and warning sounds is vital to the safety of workers in industry. High noise levels and excessive hearing protection can degrade the worker's ability to detect warning sounds and jeopardize their lives (Wilkins and Martin, 1982). Therefore, interference with speech is a particularly disturbing effect of environmental noise pollution. Good understanding of the effects of hearing protection on speech communication is especially important since HPDs are frequently used in environments requiring various forms of speech communication.

About eight years ago Etymotic Research introduced two new models of HPDs: (1) the ER-15 Musician's Earplug and (2) the ER-20 Hi-Fi Earplug (Killion, DeVilbiss, and Stewart, 1988; Allen and Berger, 1990). These HPDs were intended for rock-music and big-band musicians. Both HPDs provide moderate noise attenuation, that is, relatively independent of sound frequency in order to protect the musician's hearing while at the same time permitting musicians to hear the music they play without spectral changes introduced by typical HPDs. The ER-15 uses the compliance a diaphragm similar to a passive speaker cone and the inertance of the air mass in the sound channel to form a Helmholtz resonator with the resonant frequency around 2700 Hz. The ER-20 uses a tuned resonator and acoustic resistor.

HPDs with flat noise attenuation effectiveness across sound frequency may minimize the effect of industrial noise on speech communication and be an acceptable compromise between adequate protection against the noise and adequate speech communication. Thus, the ER-15 and ER-20 may be very well suited for hearing protection in such industrial sites where speech communication and audibility of warning signals are of primary concern.

The major problem with assessment of speech communication with HPDs is the lack of a generally accepted measure of speech communication in a noisy environment surrounding both the talker and the listener. If such a measure could be established, the effectiveness of speech communication between two people wearing the same type of hearing protectors could be represented by a "speech communication index" (SCI). Such indices may be helpful for the selection of HPDs in a noisy situation where the effectiveness of verbal, and even non-verbal, communication is of concern.

## 9. SPECIFIC AIMS

The ability to provide both facile speech communication and adequate noise attenuation should be the major consideration in the HPD selection process. Previous reports (Suter, 1989) have suggested that HPDs providing frequency independent attenuation of sound may facilitate speech communication in noisy environments while still providing sufficient noise attenuation. Limited information is available, however, about the types of noise and sound pressure ranges where such HPDs are appropriate for industrial use. Furthermore, no standardized or commonly used measure of speech communication exist that may be used to assess the speech communication loss introduced by various HPDs.

The goals of the present study were (1) to determine the feasibility of using flat-attenuation HPDs in various industrial noises and (2) to examine the adequacy of various speech communication measures for assessing speech communication efficiency between workers wearing HPDs in different acoustic environments. The specific aims of the study were:

- (1) to compare five potential measures of speech communication with HPDs in order to determine their usefulness for assessing of speech communication efficiency with HPDs,
- (2) to compare the effects of flat-attenuation earplugs (ER-15 and ER-20) and regular earplugs (EAR Ultrafit) on speech communication,
- (3) to propose a specific HPD-oriented measure of speech communication in noise,
- (4) to assess the relation between speech-communication efficiency and noise-reduction efficiency for selected flat-attenuation HPDs in various noisy environments, and
- (5) to assess the effects of flat-attenuation HPDs on speech communication in noise for wearers with high-frequency sensorineural hearing loss.

## 10. METHODOLOGY

### 10.1. SUBJECTS

Thirty normal-hearing subjects (Group NH) and thirty hearing-impaired subjects with sensorineural hearing loss (Group HI) were selected to participate in the study. All the subjects spoke English as their primary (native) language. All normal-hearing subjects were between the ages of 18 and 35 years old (mean age=21.9 years, SD=2.9 years). The normal-hearing group was comprised of 10 European Americans (mean age=22.4 years, SD=2.2 years), 10 African Americans (mean age=22.5, SD=2.0 years), and 10 Asian Americans (mean age=20.9 years, SD=3.8 years). Each of the ethnic subgroups included five male and five female subjects. The mean ages of the 15 male and 15 female subjects were 22.2 years (SD=1.5 years) and 22.6 years (SD=2.8 years), respectively.

For the purpose of the present study, subjects were considered to have normal hearing if they met the following criteria: (1) left and right ear pure-tone air-conduction thresholds less than or equal to 20 dB HL (ANSI S3.6-1989) at audiometric octave frequencies from 250 through 8000 Hz, (2) pure-tone air- and bone-conduction thresholds differing no more than 5 dB at any of the audiometric octave frequencies in range from 250 to 4000 Hz in any ear, (3) left- and right-ear tympanograms revealing normal pressure and mobility, (4) contralateral acoustic reflexes at 105 dB HL at 1000 Hz, and (5) no recent history of otologic pathology. The screening procedure included also a medical interview, determination of speech recognition thresholds (SRTs) in quiet, and determination of word recognition scores (WRSs) in quiet for the left and right ear. All results of the screening procedure were recorded on a Case History form included as Appendix C.

Hearing impaired subjects participating in this study were mostly European Americans due to the type of available population. To be included in this group, the subjects had to have air-conduction hearing thresholds no worse than 25 dB HL at the audiometric octave frequencies from 250 to 2000 Hz and thresholds of 30 dB HL or more above 2000 Hz, bilaterally. Such a configuration indicated the existence of sloping sensorineural hearing loss. In addition, all the subjects in Group HI had to have normal tympanograms, contralateral acoustic reflexes present at the levels below 105 dB HL at 1000 Hz, and less than a 5 dB difference between air- and bone-conduction pure-tone hearing thresholds at audiometric octave frequencies from 250 Hz through 4000 Hz, to rule out the presence of a conductive component to the hearing loss. The above criteria are similar to those used by Wilde and Humes (1990) for selecting subjects with sensorineural hearing loss for their study. The age of hearing-impaired subjects varied from 25 to 53 years (mean age=38.7 years, SD=10.9 years). Both the age and composition of Group HI differ from the original design proposed in the study because the researchers were unable to locate young African Americans and Asian Americans with the appropriate hearing profiles despite considerable efforts and help from several public health agencies. The above changes in the design of the study were approved by the Agency prior to the end of data collection.

## 10.2. HUMAN PROTECTION PROCEDURE

The harmful effects of noise and the purpose and procedures of the study were explained to each subject prior to testing. Oral and written explanations of the study (Appendix A) were followed by a questions-and-answers session. After all questions were answered, each subject willing to participate in the study signed the Consent Form (Appendix B). The study consisted of seven separate experiments for a total of about 12 hours. The subjects were paid \$10 per hour plus parking expenses. At the beginning of each experiment, the subjects were reminded that they should immediately interrupt the test if they experienced any pain or discomfort during participation in the study and indicate the presence of any discomforting condition to the experimenter (see Appendix D). No such event happened during the study.

### 10.3. HEARING PROTECTION DEVICES

Three different types of hearing protection devices (HPDs) were used in the study: (1) the EAR Ultrafit Earplug, (2) the ER-15 Musician's Earplug, and (3) the ER-20 Hi-Fi Earplug. The EAR Ultrafit Earplug is a three-flanged soft plastic earplug with a reported Noise Reduction Rating (NRR) of 21. Its attenuation increases with frequency from about 30 dB at 125 Hz to 45 dB at 8000 Hz. The ER-15 and ER-20 earplugs have NRRs of 11 dB and 12 dB, respectively. Both of these earplugs can be considered to be low-attenuation and flat-attenuation HPDs. The EAR Ultrafit earplug represents an attenuation profile that is typical of most existing insert HPDs and was used for reference purposes. The EAR Ultrafit and ER-20 were off-the shelf earplugs whereas the ER-15 earplugs were custom molded for each subject.

According to technical specifications, both the ER-15 and ER-20 earplugs offer approximately 15 dB noise attenuation from 125 to 8000 Hz. The ER-15 Musician's Earplug offers frequency independent attenuation ( $\pm 2$  dB) across the entire frequency range (see: Killion, DeVilbiss, and Stewart, 1988) whereas the ER-20 Hi-Fi Earplug offers a gradually increasing attenuation from about 12 dB at 125 Hz to 22 dB at 8000 Hz. The main technical difference between the ER-15 and ER-20 earplugs is that the ER-15 Musician's Earplug uses a diaphragm similar to a passive loudspeaker cone whereas ER-20 Hi-Fi Earplug uses a tuned resonator and acoustic resistor.

Bilateral earmold impressions and custom molded ER-15 earplugs were made for each subject participating in the study upon completion of an audiological evaluation. All impressions were made by certified audiologists in the Speech and Hearing Clinic at The Pennsylvania State University.

### 10.4. HEARING PROTECTION DEVICE FITTING

Three basic fitting techniques are commonly used for HPD fitting (see: Letowski, Burstein, Clark, Romanowski, and Sevec, 1995): (1) user fit, (2) informed-user fit, and (3) experimenter-assisted user fit. The user fit, based on manufacturer instructions and no additional help from the experienced HPD fitter, is considered the most realistic technique for determining the real-world attenuation of HPDs. Such a fit, however, was not considered appropriate for the present study due to the study's longitudinal character and the potential contamination of the data by a learning effect. In other words, the same subject who could be considered a naive HPD user at the beginning of the study would become a very experienced user at the end. The results of experiments conducted at the beginning and at the end of the study could not be directly compared if the subject's fitting skills had changed substantially. In addition, no manufacturer's instructions are provided for the custom molded ER-15 earplugs and some fitter's guidance is necessary during initial fitting of those HPDs. Considering the above situation, the informed-user fit was selected as the optimal solution in the present study. Specifically, all subjects were instructed by the experimenters how to insert each of the three hearing protectors prior to the beginning of the study. Experimenters demonstrated the fitting of the plugs on themselves and verbally

coached each subject during initial fittings. To help the subject determine when the HPD seal was complete, a wideband noise of 60 dB SPL was provided during fitting. However, the experimenters did not physically help the subjects to insert their HPDs. The outlined fitting procedure should have made the quality of HPD fitting relatively uniform across the whole study.

## 10.5. TEST ENVIRONMENTS

All experiments were conducted in the Speech and Hearing Clinic at The Pennsylvania State University (University Park, PA). Vocal effort measurements were made in an audiometric test room (ATR). The ambient noise levels in the room were below the levels required for hearing testing in a sound field (ANSI S3.1-1991). All other experimental data were collected in a diffuse sound-field room (DSFR) complying with ANSI S12.6-1984 (R1990) requirements and routinely used for hearing protector testing. The DSFR has a reverberation time of about one second in the 250 to 4000 Hz range and ambient noise levels suitable for hearing testing in a sound field (ANSI S3.1-1991). The room is equipped with three loudspeaker systems located in corners of the room and facing orthogonal directions. Each system consists of one woofer (ElectroVoice DL15X) and one tweeter (ElectroVoice DH1A with a EV940 horn) mounted in a custom-made plywood baffle.

## 10.6. SPEECH SIGNALS AND THEIR SOURCES

All experiments requiring listening to speech signals were conducted in the DSFR. The signals were delivered through a Heath NS103A loudspeaker located directly in front of the subject at a 1 meter distance and equalized to have relatively flat frequency response ( $\pm 5$  dB) in 100 to 10000 Hz. range. The signals were played from either a Sony CAP-X202ES compact disk player ( Experiment 3: Word Recognition Test) or a Sony TC-W435 tape deck (Experiment 4: Speech Intelligibility Rating, Experiment 5: Battleship Game Simulation, and Experiment 6: Speech Level Adjustment).

The verbal test material used in Experiment 3: Word Recognition Score (WRS) consisted of eight 50-word long lists of monosyllabic words from the Northwestern University Auditory Test No. 6 (NU-6). The lists were included on a compact disk (CD) made by the Auditory Section of the Veteran Administration Hospital, Long Beach, CA. This is the same material that was used for obtaining WRS in quiet during the initial audiological evaluation.

The speech material used in Experiment 4: Speech Intelligibility Rating and in Experiment 6: Speech Level Adjustment was a female voice recording of connected speech included on Auditec Cassette No 122. This recording has previously been used in studies on noise tolerance (Nabelek, Tucker, and Letowski, 1991; Letowski and Emanuel, 1995). The long-term average spectrum (LTAS) of the connected speech signal is shown in Figure 1.

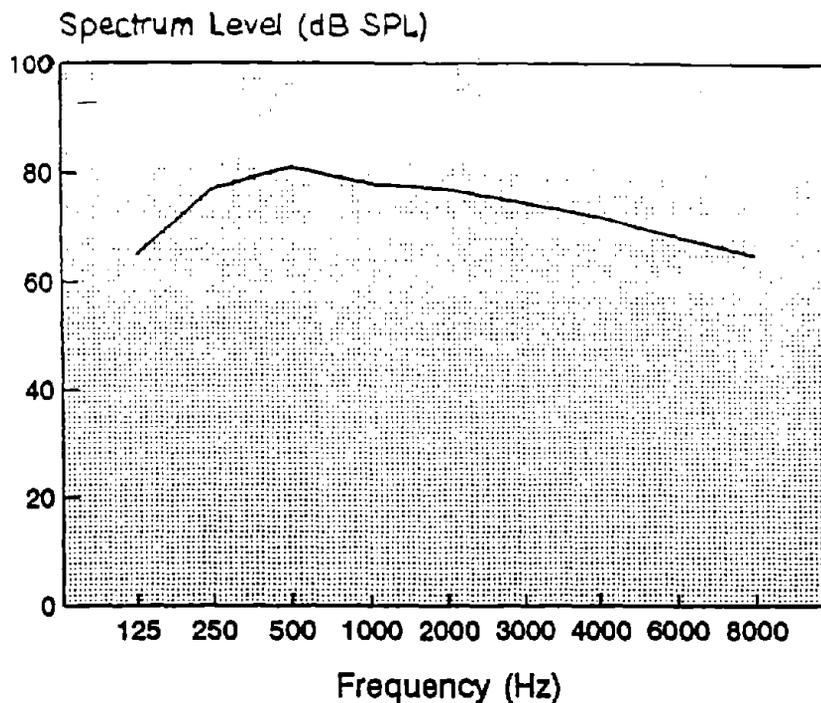


Figure. 1. Long-term average spectrum of the connected speech signal used in this study (female voice).

## 10.7. NOISE MASKERS AND THEIR SOURCES

A set of three noise maskers was used throughout the study. The noises were: (1) a wideband random noise, (2) a real word industrial noise, and (3) a simulated industrial noise. The wideband random noise (WRN) was an audiometer-generated noise with a flat long-term, average spectrum in the 100 Hz through 20,000 Hz frequency range. The industrial noise (IN) was a sample of noise recorded in the Power Plant of the Pennsylvania State University. The simulated industrial noise (SIN) was wide-band random noise with a spectral envelope matching the long-term average spectrum of the industrial noise. One-third-octave band spectra of the wideband random noise and the simulated industrial noise are shown in Figure 2. Octave band spectra of both noises are listed in Table 1. The spectra of the real-world industrial noise are not shown since they did not differ from the respective spectra of the simulated industrial noise by more than 1 dB. All noise levels were measured at the subject's location.

The three maskers used in this study were selected as representative noises to determine the effects of both spectral envelope and temporal variability of noise on communication between people wearing HPDs. Williams and Michael (1991) used recorded industrial noises in their study of speech perception with HPDs and concluded that varying temporal properties of the employed noises contributed considerably to the large variability of their data.

All the noise maskers were played from a magnetic tape through an Akai GX-A5X cassette recorder. The noise level at the listener location was kept at 85 dBA. The noise maskers used in the experiments conducted in the DSFR (Experiments 2-6) were delivered through three sets of loudspeakers built in the room. These loudspeakers were also used to deliver narrow-band test signals in Experiment 1: Real Ear Attenuation at Threshold, conducted in the same environment.

Table 1. Octave band spectra of the wideband random noise (WRN) and the simulated industrial noise (SIN) used in this study.

Center frequency (Hz)	WRN (dB)	SIN (dB)
125	60.0	75.5.0
250	63.0	70.5
500	66.0	71.5
1000	69.5	69.5
2000	74.0	73.5
4000	77.0	75.0
8000	78.0	67.5

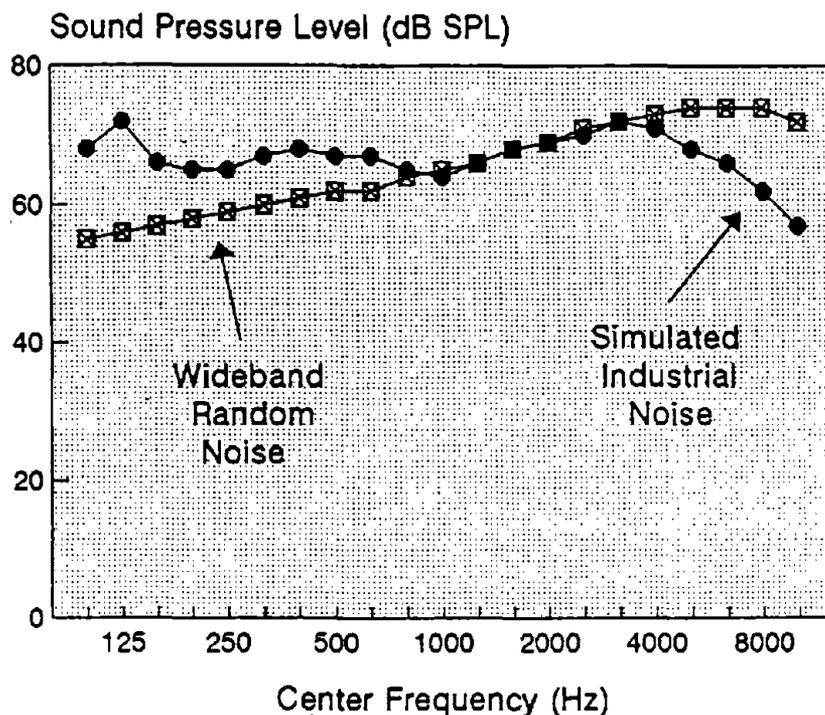


Figure 2. One-third-octave band spectra of the wideband random noise (WRN) and the simulated industrial noise (SIN) used in this study.

Noise maskers employed in Experiment 7: Vocal Effort Test were delivered by two Atlas Sound PL 150 loudspeakers (16 ohms, 150 watts) located in the two back corners of the ATR. The loudspeakers were located approximately one meter away from the subject's ears.

#### 10.8. SIGNAL LEVEL CALIBRATION

The sound pressure levels in the test rooms were calibrated at the position corresponding to the middle of the subject's head using the substitution method. The rms levels of individual signals and maskers were measured using a B&K 2113 audio frequency spectrometer, a B&K 4144 condenser microphone, and a B&K 2619 microphone preamplifier. Both the speech and noise sounds were adjusted to 85 dBA levels at the listener location with the subject absent. These level were kept constant across all experiments unless the noise level was under the subject's control.

Vocal effort measurements were made with a throat microphone connected to a digital storage system (Tucker-Davis-Technologies System II). The calibration procedure for the throat microphone was to determine the force and acceleration levels needed to achieve a 0 dBVU reading on the TEAC X-2000R tape recorder. For calibration purposes, the microphone input with the input level control set to 3/4 of the scale was used. The microphone (RACAL) was driven from a pure tone source (B&K 1022 BFO) through a shaker (B&K 4810) with its attached impedance head (B&K 8000). The microphone was held to the surface of the impedance head by rubber bands that provided a static force of 3N. Both the acceleration and force outputs of the impedance head were connected to the appropriate inputs of a charge amplifier (B&K 2651) whose output was monitored by a measuring amplifier (B&K 2113) and the TDT system. At the main resonance of the unit (400 Hz) the drive to the shaker was adjusted to give 0 dBVU on the tape recorder. At these conditions the voltage output of the charge amplifier was converted to force and acceleration. These values were: 0.0774 N or -22.2 dB re 1 N and 0.0643 m/s or -23.8 dB re 1 m/s.

#### 10.9. EXPERIMENTAL DESIGN: TEST AND RETEST SESSIONS

Experiments 3 through 7 included both a test session and a retest session. Experiments 1 and 2 had no retest session due to their standardized character. The duration of a test session was about 1 hour and never exceeded 1.5 hour including all the breaks needed by the subject. During the test session all three HPDs and three noise conditions were presented in a counterbalanced order according to the Greek-Latin experimental design procedure. The no-HPD condition always preceded the HPD condition. No tests were conducted in quiet except for the initial audiological evaluation tests. When word lists were used, they were independently counterbalanced to avoid potential contamination of the data by a fixed order of list presentation. Retest sessions were limited to wideband random noise masker. The order of HPDs during

the retest session was the reverse of the order used with a given subject for the wideband noise masker in the test session.

## 10.10. PROCEDURES

### 10.10.1. AUDIOLOGICAL EVALUATION

Certified audiologists in the Speech and Hearing Clinic at The Pennsylvania State University conducted the initial audiologic evaluation of subjects to determine acceptance into the study. The evaluation included a case history interview, an otoscopic evaluation, and both pure-tone and speech hearing tests. Audiometric testing was conducted using a Beltone model 2000 clinical audiometer with TDH-50 earphones calibrated according to ANSI S3.6-1989 standard. Testing was done in an audiometric testing room that met criteria for free field hearing testing (ANSI S3.1-1991). Pure-tone air conduction thresholds were obtained for each subject at octave frequencies from 250 Hz through 8000 Hz. Two half-octave frequencies (3000 Hz and 6000 Hz) were also included. Pure-tone bone conduction thresholds were obtained for any subject whose air conduction thresholds exceeded 20 dB HL at any frequency. Impedance measurements were made with the EarScan middle ear analyzer from Micro Audiometrics. A 226 Hz standard probe tone was used. Subject inclusion criteria were tympanogram compliance between 0.2 to 1.5 ml and present acoustic reflexes contralaterally at 1000 Hz at 105 dB SPL.

Spondaic words (Northwestern University List) were used to obtain a speech reception threshold (SRT) in quiet for each subject. Word recognition scores (WRS) in quiet were obtained with the monosyllabic 50-word lists (1B-4B) from Northwestern University (NU-6). The words were spoken by a female talker with a carrier phrase "Say the word \_\_\_\_\_". The lists were taken from a compact disk (CD) made by the Auditory Section of the Veteran Administration Hospital, Long Beach, CA. The presentation level of the NU-6 words was 40 dB above the SRT level for individual subjects.

### 10.10.2. EXPERIMENT 1: REAL EAR ATTENUATION AT THRESHOLD

The Real Ear Attenuation at Threshold (REAT) Test was conducted in the DSFR described in Section 10.5. The procedure followed the ANSI S12.6-1984 standard. The only exception was that the HPDs were fitted by the subjects themselves rather than by the experimenter. Custom-made digital equipment (Michael, 1990) was used to generate the one-third-octave-band test signals. The signals were delivered through the three loudspeakers systems described in Section 10.5. The test signals were pulsed one-third octave noises (250 ms on/off time and 40 ms rise/decay time) with center frequencies of 125, 250, 500, 1000, 2000, 3150, 4000, 6300, and 8000 Hz. The experiment was controlled by a Gateway 2000 4DX2-66V personal computer through a custom-written software program.

A Michael DT-2 digital attenuator was used to control the level of the test signal according to the subject's responses. Another custom-written software program was used to record subjects' responses and associated signal changes and store them on the Gateway 2000 4DX2-66V computer.

During the REAT test the subjects were seated in the test room with or without HPDs and instructed to press the response button as long as the stimulus was audible and to release the button when the stimulus was not audible. The point at which the subject pressed or released the button was called a *reversal* and the actual signal level associated with the *reversal* was recorded. Each one-third-octave band stimulus was presented to the subject until ten reversals were recorded. All three HPDs described in Section 10.3 were evaluated in one session that ranged from 1 to 2.5 hours, depending on the subject's ability to keep the test signal close to threshold and the need for breaks. Each HPD test was preceded by a reference run with no HPDs. The difference in hearing thresholds measured without and with HPDs was considered the REAT value and calculated from the recorded data at each test frequency. Due to the degree of their hearing impairment, some subjects were not able to hear all of the test signals when wearing HPDs, even when the signal was played at the highest possible level. Such subjects were excused from this portion of the study and their data were not recorded. The subject instruction form is included in Appendix D.

#### 10.10.3. EXPERIMENT 2: SOUND PRESSURE ATTENUATION IN REAL EAR

The Sound Pressure Attenuation in Real Ear (SPARE) test was administered to measure the actual reduction in the sound pressure level in the ear canal due to the insertion of a HPD. The test was conducted in the DSFR environment. The test signal was a wideband random noise presented at 85 dBA at the subject's head location. The sound pressure level in the ear canal was measured using an Etymotic Research ER-7C probe microphone. The ER-7C microphone has a flat frequency response extended beyond 10 kHz ( $\pm 2.5$  dB), small diameter tubing (0.95 mm external diameter and 0.5 mm internal diameter), and wide dynamic range (55 dB SPL to 125 dB SPL). The microphone tubing was inserted 25 mm into the ear canal (re: antitragus notch) either by itself (condition OPEN) or together with the a HPD (condition CLOSED). The tubing was inserted along the ear canal wall and the earplug was slid in with tubing held in place by the experimenter. The 25 mm depth of tubing insertion was sufficient in all cases for the probe tip to extend slightly beyond the end of the earplug. The difference in dBA readings for the OPEN and CLOSED test conditions was recorded as the sound pressure level reduction in decibels (dBs) by a given HPD (ANSI S3.19-1974). The subject instruction form is included in Appendix D.

#### 10.10.4. EXPERIMENT 3: WORD RECOGNITION SCORE

The Word Recognition Score (WRS) was chosen to serve as an external validity criterion for Experiments 4-6. The monosyllabic speech test (NU-6 Test) was employed

on the assumption that speech communication in noise usually depends on single words or limited phrases. Words were presented at a level of 85 dBA at the subject's head location and at a signal-to-noise ratio (SNR) of 0 dB. Each subject was seated in the middle of the test room (DSFR) approximately one meter from all sound sources. During the test, subjects listen to target words presented with the carrier phrase "Say the word \_\_\_\_\_" and were asked to write down target words on a response form. Subjects were encouraged to guess if they were unsure of the word. The hearing protection devices and types of noise were counterbalanced to eliminate any order effects. Similarly, word lists were independently counterbalanced to eliminate the effect of order on collected data. The WRS data without HPDs (No-HPD condition) were always collected at the beginning of testing with counterbalanced presentation of noises. The subject instruction form is included in Appendix D.

#### 10.10.5. EXPERIMENT 4: SPEECH INTELLIGIBILITY RATING

The Speech Intelligibility Rating (SIR) served as a criterion for the subject's self-assessment of speech recognition efficiency while wearing the HPDs in various noisy environments. Connected speech material read by a female talker was used as a test signal. The subject listened to the speech signal for 60 seconds and was asked to judge speech intelligibility on a graphic rating scale that extended from 0% (I could not understand anything) to 100% (I could understand everything). Different 60s long fragments of the same recording were randomly selected for various HPDs and noises. The test was also given under a No-HPD condition, that is, without HPDs. The subject instruction and answer forms are included in Appendix D.

#### 10.10.6. EXPERIMENT 5: SIMULATED BATTLESHIP GAME

The Simulated Battleship Game (SBG) was used to assess communication between two persons wearing HPDs. At the beginning of the test session, the experimenter presented a set of 20 coordinates to the subject through the Heath NS102N. The subject was seated in the center of the room facing the loudspeaker and listened to coordinates in a background of 85 dBA wideband random noise without HPDs. The purpose of this part of the experiment was to determine a baseline condition for speech produced in noise. In the main part of the experiment two subjects wearing the same type of HPDs (or without HPDs) were seated in the middle of the room, facing each other with an acoustically transparent cloth between them. The subjects alternated in giving and receiving 20 predetermined coordinates for each test condition. The subject's task was to read battleship game coordinates (e.g. A-5) from a provided sequential list of coordinates and to record on an answer sheet the coordinates spoken by the other subject. The subjects alternated 20 times for each test condition. The order of speaking was determined by a coin flip. The subjects were encouraged to speak loud and clear to help their partners recognize the coordinates. All HPD conditions and noises were counterbalanced. The No-HPD condition was always presented first. The subject instruction form is included in Appendix D.

### 10.10.7. EXPERIMENT 6: SPEECH LEVEL ADJUSTMENT

The Speech Level Adjustment (SLA) task employed the same Auditec recording of running speech (female voice) that was used in Experiment 4: Speech Intelligibility Rating. The subject was asked to determine the most comfortable listening level (MCLL) for speech presented in constant level noise while wearing different HPDs and without HPDs. The HPDs (Ultrafit, ER-14, and ER-20) and types of noise (WRN, IN, and SIN) were presented in a counterbalanced order and were preceded by No-HPD conditions. Three most comfortable listening level measurements were obtained for each subject and test condition via a bracketing technique using 1 dB steps. The median of the three MCLL measurements for each condition was recorded for further analysis. The subject instruction form is included in Appendix D.

### 10.10.8. EXPERIMENT 7: VOCAL EFFORT TEST

The Vocal Effort Test (VET) was used to determine whether different HPDs could affect the intensity and fundamental frequency of vocal production. Subjects were asked to read aloud a one minute continuous discourse passage and to speak out three SBG coordinates while sitting in three different noisy environments. The vocal output was monitored with a RACAL throat microphone directly attached to the subject's neck. The speech signal received by the microphone was recorded on a professional quality reel-to-reel TEAC X-2000R tape recorder and subsequently analyzed. For each type of noise laryngeal voice recordings (LVR) were obtained for each subject while wearing each HPD and without a HPD.

During the VET the subject was seated in the center of the ATR with noise delivered from two Atlas Sound PL 150 loudspeakers located at 1 meter distance at 135° and 225 azimuth, re the position directly in front of the subject. The throat microphone was positioned at the subject's thyroid cartilage and strapped to the subject's neck. An auxiliary microphone was located in the center of the room directly above the subject's head for communication purposes and to monitor the noise level in the room. The input levels to the tape recorder were adjusted so that the tape recorder's VU-meters would read 0 dBVU with normal conversational speech received via the auxiliary microphone and with maximum sustained vocal effort for speech received from the throat microphone. These input settings were identical for each subject. To make sure that the recorded signal will not be occasionally distorted due to overdriving the recorder's input, the output of the throat microphone was monitored throughout the signal collection. The subject instructions are included in Appendix D.

Before data collection subjects familiarized themselves with the text of the passage to be read. Unfamiliar words were discussed so that the subjects would not stumble over pronunciation. The three masking noises and three HPDs were presented in a counterbalanced order to each subject. The No-HPD condition was presented at the beginning of each new masking noise. During each test condition the subject was asked to read the text and to vocalize the set of three SBG coordinates - E-3, O-4, and

U-2. At the end of the recording session the test conditions involving wideband random noise masker were repeated to determine the reliability of collected speech samples.

### 10.10.9. DATA ANALYSIS

Analysis of the data sets obtained in this study was based on a mixed design and repeated measure analyses of variance (ANOVA). All probability levels for factors with more than two functional levels were adjusted using Greenhouse-Geisser Epsilon to compensate for multiple comparisons (Greenhouse and Geisser, 1959). In addition, to compensate for terminal nonlinearities of percentage scale, the data sets in Experiments 3 and 4 have been linearized using arcsine transformation prior to submitting them to ANOVA (Studebaker, 1985).

## 11. RESULTS AND DATA ANALYSIS

### 11.1. AUDIOLOGICAL EVALUATION

Mean hearing thresholds, SRTs, and WRSs in quiet obtained for NH and HI subjects during audiological evaluation are shown in Table 2 and additionally illustrated in Figure 3. The data are shown separately for the left and right ear. No comprehensive measure of the overall hearing loss was used in this study.

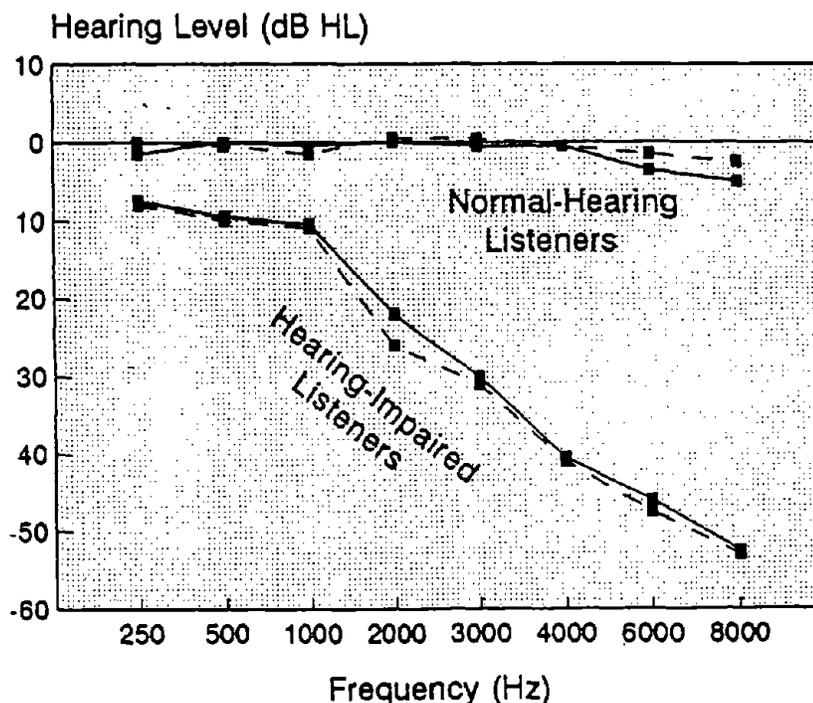


Figure 3. Threshold of hearing for left (solid line) and right (broken line) ear in normal-hearing (n=30) and hearing-impaired (n=30) listeners.

Table 2. Mean (M, dB HL) and standard deviation (SD, dB) values for the threshold of hearing at 250 through 8000 Hz audiometric frequencies, speech recognition threshold (SRT, dB HL), and word recognition scores (WRS, %) in quiet obtained for two groups of subjects participating in the study. Data are listed separately for right and left ear.

Frequency (Hz)		Group NH		Group HI	
		Right Ear	Left Ear	Right Ear	Left Ear
250	M	1.5	0.2	7.8	8.2
	SD	4.0	4.2	6.3	5.9
500	M	-0.2	0.5	9.5	10.2
	SD	3.8	3.6	6.6	6.1
1000	M	0.7	1.7	10.3	11.2
	SD	5.0	3.6	7.3	7.0
2000	M	0.0	-0.7	21.8	25.8
	SD	5.4	4.3	17.9	18.8
3000	M	0.3	-0.7	30.3	30.8
	SD	3.7	3.7	16.8	17.9
4000	M	0.4	0.5	40.7	41.0
	SD	5.2	4.8	19.2	18.7
6000	M	3.5	1.5	46.2	47.5
	SD	5.4	5.4	19.6	20.5
8000	M	5.2	2.7	52.7	53.0
	SD	6.2	5.8	19.1	18.5
SRT	M	0.5	1.0	11.5	11.0
	SD	4.0	3.6	11.1	11.5
WRS	M	99.9	99.6	95.1	92.8
	SD	0.7	1.6	6.1	7.5

Inspection of the audiometric data contained in the table and the graph indicates: (1) a close similarity between right and left ear hearing thresholds in both groups, (2) a flat 10 dB HL hearing loss at and below 1000 Hz and a sloping 10 dB/oct high frequency hearing loss above 1000 Hz in HI subjects, and (3) a flat 0 dB HL average hearing loss across all audiometric frequencies in NH subjects. Average speech reception thresholds (SRTs) for NH and HI subjects were 0 and 10 dB HL, respectively. This indicates that HI subjects had typically marginal-to-moderate hearing loss in terms of speech perception for spondaic words. The word recognition scores (WRSs) obtained at 40 dB sensation level (SL), i.e., 40 dB above the threshold, were relatively similar in both groups and seldom lower than 80%. The average WRSs were practically 100% for NH subjects and 92.8 and 95.1% for left and right ear of HI subjects, respectively.

Standard deviation values of hearing thresholds obtained for NH subjects are frequency independent across the entire audiometric range and typical for pure-tone audiometric tests of normally hearing subjects. Standard deviation values for hearing thresholds above 1000 Hz in HI subjects are relatively large indicating a lack of homogeneity of the group re: the amount of the hearing loss. Such a situation, however, was unavoidable due to the specific requirements of the study.

The threshold data for normal-hearing subjects were subjected to an analysis of variance (ANOVA) with repeated measures on GENDER (male, female) and ETHNICITY (African, Asian, and European Americans). None of these factors had a significant effect on threshold data (GENDER:  $F=0.45$ ,  $df=1/24$ ,  $p=0.5$ ; ETHNICITY:  $F=0.004$ ;  $df=2/24$ ,  $p=0.99$ ). Additionally, SRT and WRS values were very similar across gender and ethnic backgrounds.

## 11.2. EXPERIMENT 1: REAL EAR ATTENUATION AT THRESHOLD

The average REAT data for HPDs tested in this study are shown in Table 3. The table includes REAT values calculated for the whole group of 60 subjects and for NH and HI groups separately. A mixed design ANOVA on HEARING (Group NH, Group HI) with repeated measures on HPD (No-HPD, Ultrafit, ER-15, ER-20) and FREQUENCY (nine test frequencies) showed statistically significant effects of HPD ( $F=21.39$ ,  $df=2/92$ ,  $p<0.01$ ), FREQUENCY ( $F=80.07$ ,  $df=8/368$ ,  $p<0.01$ ), HPDxFREQUENCY ( $F=18.56$ ,  $df=16/736$ ,  $p<0.01$ ), and HEARINGxFREQUENCY ( $F=2.83$ ,  $df=8/368$ ,  $p=0.02$ ) on REAT values. The HEARING factor was not significant ( $F=0.70$ ,  $df=1/46$ ,  $p=0.41$ ) and there were no other significant interactions.

It is important to notice that NH and HI subjects demonstrated near identical REAT values for ER-15 earplug with differences normally less than 1 dB. Conversely, the data for ER-20 earplug are parallel-shifted by about 3 dB with the HI subjects showing higher REAT values. The REAT values obtained by both groups for Ultrafit earplug are in close agreement for all frequencies except 3000 and 4000 Hz where HI subjects' data showed about 4 dB larger attenuation.

The REAT values for ER-15 and ER-20 earplugs obtained with NH listeners show good agreement with the manufacturer's data. Typically, the difference does not exceed 2 dB. Notable discrepancies are at 500 Hz (4.5 dB) and 1000 Hz (4.2 dB) for the ER-20 earplug. The data for the E.A.R.<sup>TM</sup> Ultrafit plug, however, are on the average 10 dB lower than those published by the manufacturer. In addition, the noise reduction rating (NRR) values for all three HPDs were in order of 0 to -2 dB due to the large variability of the data.

The gender and ethnicity effects on REAT test data for normal-hearing listeners were assessed by a mixed design ANOVA on GENDER (male, female) and ETHNICITY (African, Asian, and European Americans) with repeated measures on HPD (No-HPD, Ultrafit, ER-15, ER-20) and FREQUENCY (nine test frequencies). The HPD and FREQUENCY factors and the HPDxFREQUENCY interaction were, as before, highly significant ( $p<0.01$ ). However, neither GENDER ( $F=2.02$ ,  $df=1/24$ ,  $p=0.17$ ),

ETHNICITY ( $F=1.45$ ,  $df=2/24$ ,  $p=0.25$ ), nor their interactions had statistically significant effects on REAT values.

Table 3. Real Ear Attenuation at Threshold (REAT) data for Ultrafit, ER-15, and ER-20 earplugs. Mean (M, dB) and standard deviation (SD, dB) values calculated for all 60 subjects (ALL) and NH and HI subjects separately.

Frequency (Hz)		Hearing Protection Device								
		Ultrafit			ER-15			ER-20		
		Group NH	Group HI	ALL	Group NH	Group HI	ALL	Group NH	Group HI	ALL
125	M	17.1	17.2	17.2	14.2	15.0	14.5	14.5	17.6	15.7
	SD	8.9	9.5	9.0	8.3	10.4	9.1	8.0	6.5	7.6
250	M	17.6	15.9	16.9	12.8	12.2	12.5	14.6	16.4	15.3
	SD	9.1	10.8	9.7	6.7	8.0	7.1	7.9	8.0	7.9
500	M	16.3	14.9	15.8	12.5	12.2	12.4	13.7	16.0	14.6
	SD	9.3	10.7	9.8	6.8	8.5	7.4	9.0	8.2	8.7
1000	M	17.0	15.7	16.5	13.0	12.5	12.7	14.7	18.3	16.1
	SD	8.5	11.3	9.5	6.1	7.7	6.7	7.5	7.9	7.8
2000	M	24.8	23.6	24.3	14.0	12.7	13.5	21.7	25.4	23.1
	SD	9.6	12.4	10.6	7.1	7.8	7.3	9.7	8.0	9.2
3000	M	25.6	29.5	27.1	15.2	16.9	15.8	24.3	30.0	26.4
	SD	9.8	10.2	10.0	6.4	6.5	6.5	7.8	6.2	7.7
4000	M	23.1	27.7	24.8	13.0	13.9	13.3	19.4	24.4	21.2
	SD	10.4	11.3	10.9	5.9	5.3	5.6	7.2	5.6	7.0
6000	M	27.7	28.6	28.0	15.2	17.2	16.0	21.7	24.1	22.6
	SD	13.0	13.1	12.9	6.5	7.3	6.8	8.2	8.8	8.4
8000	M	29.3	31.0	29.9	18.3	18.0	18.2	23.2	29.0	25.4
	SD	13.3	15.1	13.8	7.2	6.9	7.0	9.4	9.2	9.7

### 11.3. EXPERIMENT 2: SOUND PRESSURE ATTENUATION IN REAL EAR

Mean and standard deviation values for sound pressure reduction (SPARE) caused by an insertion of a HPD into the ear canal are listed in Table 3. The data in Table 4 have been averaged across all subjects.

A mixed design ANOVA on HEARING (Group NH, Group HI) with repeated measures on HPD (Ultrafit, ER-15, ER-20) and NOISE (wideband, industrial, and simulated noise) did not reveal any statistically significant effects except for HPD ( $F=14.42$ ,  $df=2/116$ ,  $p<0.01$ ). Post-hoc analysis of HPD conditions indicated that all differences in attenuations offered by the three earplugs were statistically significant at least at  $p=0.017$  level. The HEARING ( $F=0.14$   $df=1/58$ ,  $p=0.71$ ) and NOISE ( $F=1.04$ ,

df=2/116, p=0.34) effects and all the interactions were not significant. Table 4. Sound Pressure Attenuation in Real Ear (SPARE) data for Ultrafit, ER-15, and ER-20 earplugs. Mean (M, dB) and standard deviation (SD, dB) values calculated for all 60 subjects.

Type of Hearing Protection Device		Type of noise		
		Industrial Noise	Simulated Noise	Wideband Noise
Ultrafit	M	10.3	10.2	10.0
	SD	4.5	4.4	4.4
ER-15	M	13.0	13.1	12.9
	SD	3.5	3.8	3.7
ER-20	M	11.8	11.6	11.3
	SD	4.7	4.7	4.6

The gender and ethnicity effects on SPARE data for normal-hearing listeners were assessed by a mixed design ANOVA on GENDER (male, female) and ETHNICITY (African, Asian, and European Americans) with repeated measures on HPD (Ultrafit, ER-15, ER-20) and NOISE (wideband, industrial, and simulated noise). Both GENDER ( $F=2.72$ ,  $df=1/24$ ,  $p=0.11$ ) and ETHNICITY ( $F=0.64$ ,  $df=2/24$ ,  $p=0.54$ ) effects were not significant. The effect of HPD ( $F=3.50$ ,  $df=2/48$ ,  $p=0.04$ ) was, as before, significant. No statistically significant interaction among factors was found.

It is noteworthy that ER-15 earplug, considered as the least effective HPD tested in this study, resulted in the highest SPARE values for all three types of noise. Both the Ultrafit and ER-20 had their SPARE values much below their theoretical NRR values, although sound pressure measurements in the ear canal result usually an overestimation of real attenuation. This indicates that the insertion of the probe microphone tubing into the ear canal compromised the HPD's attenuation. Therefore, the SPARE differences among HPDs should be interpreted with caution. All other factors studied in this experiment should be relatively unaffected by the probe insertion.

To assess the reliability of SPARE measurements, all tests were repeated for a randomly selected group of five subjects. The repeated measure ANOVA on TEST (test, retest), HPD (Ultrafit, ER-15, ER-20) and NOISE (wideband, industrial, and simulated noise) factors did not reveal any statistically significant differences between test and retest data ( $F=3.74$ ,  $df=1/4$ ,  $p=0.13$ ). The actual differences between repeated readings were usually within 2 dB and always in 3 dB range. All other main factors and their interactions were also non significant ( $p>0.3$ ).

#### 11.4. EXPERIMENT 3: WORD RECOGNITION SCORE

Word recognition scores (WRSs) are listed in Table 5. The data are reported separately for the NH and HI subjects, the type of masking noise, and the type of HPD.

Despite a large variety of experimental conditions, the WRSs revealed that NU-6 monosyllabic words presented at 85 dBA level with 0 dB SNR were similarly recognizable in all test conditions. The mean WRSs ranged from 20 to 25% across all test conditions, which indicates that speech communication at 0 dB SNR is hardly possible. Word recognition scores were independent of wearing or not wearing hearing protection, the type of protector, and the type of masking noise. A mixed design ANOVA on HEARING (Group NH, Group HI) with repeated measures on TEST (test, retest) and HPD (No-HPD, Ultrafit, ER-15, ER-20) factors for wideband random noise masker did not show any significant effect of main factors (HEARING:  $F=0.67$ ,  $df=1/58$ ,  $p=0.42$ ; TEST:  $F=1.9$ ,  $df=1/58$ ,  $p=0.17$ ; HPD:  $F=1.60$ ,  $df=3/174$ ,  $p=0.20$ ) or their interactions. Another ANOVA with an added NOISE factor (wideband, industrial, and simulated noise) but limited only to the test data (retest was made for one type of noise only) showed again no significant effect of any of the main factors (HEARING:  $F=0.001$ ,  $df=1/58$ ,  $p=0.99$ ; HPD:  $F=0.69$ ,  $df=3/174$ ,  $p=0.56$ ; NOISE:  $F=1.09$ ,  $df=2/116$ ,  $p=0.34$ ). However, there were statistically significant interactions between HPD and HEARING ( $F=3.12$ ,  $df=3/174$ ,  $p=0.038$ ) and HPD and NOISE ( $F=3.63$ ,  $df=6/348$ ,  $p=0.003$ ). This result simply indicates that some combinations of HPD and NOISE and HPD and HEARING are less desirable for word recognition than others. A similar ANOVA without the No-HPD condition gave practically the same results.

Table 5. Mean (M, %) and standard deviation (SD, %) values for word recognition scores (WRS) obtained in this study by NH and HI subjects for various listening conditions.

Type of Hearing Protection Device	Normal-Hearing Listeners				Hearing-Impaired Listeners			
	Type of noise				Type of noise			
	Industrial Noise	Simulated Industrial Noise	Wideband Noise (test)	Wideband Noise (retest)	Industrial Noise	Simulated Industrial Noise	Wideband Noise (test)	Wideband Noise (retest)
No-HPD M	20.0	21.3	20.5	22.1	21.5	22.8	21.5	19.8
SD	11.3	12.4	11.6	11.6	9.8	10.6	10.3	8.1
Ultrafit M	21.7	20.0	21.9	23.5	21.1	20.8	19.7	20.9
SD	12.1	11.9	11.9	11.2	10.9	10.4	9.9	9.3
ER-15 M	19.2	21.3	20.7	24.6	22.2	21.9	22.1	21.8
SD	12.0	11.6	11.0	10.6	10.0	10.5	10.3	9.1
ER-20 M	22.6	20.2	23.8	25.3	22.4	19.5	21.5	20.9
SD	11.9	12.2	10.6	11.3	10.2	10.0	10.7	9.9

The gender and ethnic background effects on WRSs for normal-hearing listeners were assessed by a mixed design ANOVA on GENDER (male, female) and ETHNICITY (African, Asian, and European Americans) with repeated measures on HPD (No-HPD, Ultrafit, ER-15, ER-20) and NOISE (wideband, industrial, and simulated noise). None of these four main factors showed a statistically significant

effect on WRSs (GENDER:  $F=0.69$ ,  $df=1/24$ ,  $p=0.41$ ; ETHNICITY:  $F=0.35$ ,  $df=2/24$ ,  $p=0.68$ ; HPD:  $F=2.48$ ,  $df=3/72$ ,  $p=0.08$ ; NOISE:  $F=2.64$ ,  $df=2/48$ ,  $p=0.09$ ). Again, however, the interaction between HPD and NOISE was statistically significant ( $F=0.79$ ,  $df=6/144$ ,  $p=0.022$ ).

#### 11.5. EXPERIMENT 4: SPEECH INTELLIGIBILITY RATING

Mean speech intelligibility rating (SIR) scores and their standard deviations are listed in Table 6. The table organization is identical to that of Table 5 as is the data analysis scheme. A mixed design ANOVA on HEARING (Group NH, Group HI) with repeated measures on HPD (No-HPD, Ultrafit, ER-15, ER-20) and NOISE (wideband, industrial, and simulated noise) factors did not reveal any significant effect of the main factors (HEARING:  $F=0.05$ ,  $df=1/58$ ,  $p=0.82$ ; HPD:  $F=0.43$ ,  $df=3/174$ ,  $p=0.73$ ; NOISE:  $F=0.06$ ,  $df=2/116$ ,  $p=0.94$ ) or their interactions. A similar ANOVA limited to wideband random noise but including the TEST factor (test, retest) did not show significant effects of either TEST ( $F=0.31$ ,  $df=1/58$ ,  $p=0.58$ ), HEARING ( $F=0.10$ ,  $df=1/58$ ,  $p=0.76$ ), or HPD ( $F=1.79$ ,  $df=3/174$ ,  $p=0.16$ ). The interactions between the main factors also were not statistically significant.

Table 6. Mean (M, %) and standard deviation (SD, %) values for speech intelligibility rating (SIR). The data are listed separately for NH and HI subjects and for various listening conditions.

Type of Hearing Protection Device	Normal-Hearing Listeners				Hearing-Impaired Listeners			
	Industrial Noise	Simulated Industrial Noise	Wideband Noise (test)	Wideband Noise (retest)	Industrial Noise	Simulated Industrial Noise	Wideband Noise (test)	Wideband Noise (retest)
No-HPD M	74.7	76.9	75.9	74.3	76.9	73.8	73.3	77.2
SD	26.2	27.3	23.2	25.0	20.9	24.1	21.4	21.1
Ultrafit M	74.1	75.3	76.3	76.1	75.0	75.6	74.6	75.5
SD	26.7	25.0	26.0	22.9	24.1	24.8	25.2	20.1
ER-15 M	73.5	77.3	76.2	78.1	77.8	74.6	77.0	77.2
SD	24.3	25.8	25.2	23.4	23.8	21.3	23.1	24.8
ER-20 M	75.6	74.5	77.0	74.3	74.6	73.0	73.4	74.8
SD	25.2	27.1	25.4	23.8	24.0	22.6	22.9	23.3

Inspection of Table 6 reveals a large dispersion of results for all test conditions. There is no doubt that SIR was a difficult test for all subjects who frequently expressed their frustration by giving odd ratings, e.g. 69%, and complaining about the task.

The gender and ethnicity effects on SIRs made by normal-hearing listeners were assessed by a mixed design ANOVA on GENDER (male, female) and ETHNICITY

(African, Asian, and European Americans) with repeated measures on HPD (No-HPD, Ultrafit, ER-15, ER-20) and NOISE (wideband, industrial, and simulated noise) factors. None of these four main factors or their interactions had a statistically significant effect on SIRs (GENDER:  $F=4.46$ ,  $df=1/24$ ,  $p=0.052$ ; ETHNICITY:  $F=2.33$ ,  $df=2/24$ ,  $p=0.12$ ; HPD:  $F=0.09$ ,  $df=3/72$ ,  $p=0.97$ ; NOISE:  $F=0.91$ ,  $df=2/48$ ,  $p=0.40$ ).

### 11.6. EXPERIMENT 5: SIMULATED BATTLESHIP GAME

The Simulated Battleship Game (SBG) data are presented in Table 7. The mean and standard deviation values of correct responses are listed separately for NH and HI subjects due to a significant effect of the HEARING factor on SBG data. The baseline performance data were obtained for coordinates spoken in quiet by the experimenter with a trained voice and subsequently reproduced in noisy environment by a loudspeaker. The baseline data were 97.0% (SD=5.5%) for NH subjects and 94.4% (SD=11.5%) for HI subjects. In both cases, the subjects were listening without HPDs.

A mixed design ANOVA on HEARING (Group NH, Group HI) with repeated measures on HPD (No-HPD, Ultrafit, ER-15, ER-20) and NOISE (wideband, industrial, and simulated noise) factors revealed significant effects of HEARING ( $F=4.20$ ,  $df=1/58$ ,  $p=0.04$ ) and HPD ( $F=12.73$ ,  $df=3/174$ ,  $p<0.01$ ) but no significant NOISE effect ( $F=2.99$ ,  $df=2/116$ ,  $p=0.06$ ) on SBG data. All factor interactions also were not significant.

Table 7. Mean (M, %) and standard deviation (SD, %) values of correct responses obtained by subjects in the Simulated Battleship Game (SBG). The data are listed separately for NH and HI subjects and for various listening conditions.

Type of Hearing Protection Device	Normal-Hearing Listeners				Hearing-Impaired Listeners			
	Industrial Noise	Simulated Industrial Noise	Wideband Noise (test)	Wideband Noise (retest)	Industrial Noise	Simulated Industrial Noise	Wideband Noise (test)	Wideband Noise (retest)
No-HPD M	82.0	81.7	85.4	84.2	75.5	75.5	75.4	78.7
SD	17.3	14.0	10.7	11.3	22.7	23.8	23.9	23.9
Ultrafit M	77.9	76.9	78.9	79.7	67.5	64.9	68.0	68.2
SD	13.8	18.6	17.5	16.0	24.5	27.8	22.5	23.6
ER-15 M	77.2	78.0	80.5	81.9	70.4	74.6	71.7	73.0
SD	16.4	21.3	12.5	10.5	23.8	24.4	23.5	21.8
ER-20 M	79.2	75.9	78.2	80.9	69.4	64.5	68.9	66.5
SD	14.4	16.0	13.4	13.9	25.1	26.9	23.5	22.7

The exclusion of the No-HPD condition from the ANOVA analysis caused the HPD factor to become not significant ( $F=1.17$ ,  $df=2/116$ ,  $p=0.31$ ). This indicates a significant difference in SBG scores for protected and unprotected ears but no significant effect of HPD on SBG scores. No other factor or factor interaction were affected by the elimination of the No-HPD condition.

An ANOVA limited to wideband random noise but including the TEST factor (test, retest) did not show a significant effect of TEST ( $F=3.39$ ,  $df=1/58$ ,  $p=0.07$ ) but confirmed significant effects of HEARING ( $F=4.68$ ,  $df=1/58$ ,  $p=0.03$ ) and HPD ( $F=11.14$ ,  $df=3/174$ ,  $p<0.01$ ). The interactions between the main factors were not statistically significant. Elimination of the No-HPD condition from the analysis made the HPD factor not significant ( $F=2.59$ ,  $df=2/116$ ,  $p=0.08$ ). No other factor or factor interaction was affected.

The gender and ethnicity effects on SBG scores for normal-hearing listeners were assessed by a mixed design ANOVA on GENDER (male, female) and ETHNICITY (African, Asian, and European Americans) with repeated measures on HPD (No-HPD, Ultrafit, ER-15, ER-20) and NOISE (wideband, industrial, and simulated noise). The analysis revealed that HPD ( $F=4.30$ ,  $df=3/72$ ,  $p=0.01$ ) and ETHNICITY ( $F=6.04$ ,  $df=2/24$ ,  $p=0.01$ ) had statistically significant effects on SBG scores. Two other main factors, GENDER ( $F=0.08$ ,  $df=1/24$ ,  $p=0.78$ ) and NOISE ( $F=2.08$ ,  $df=2/48$ ,  $p=0.15$ ), and all factor interactions were not significant. The same ANOVA performed without the No-HPD condition did not show a significant effect of the HPD factor ( $F=0.12$ ,  $df=2/48$ ,  $p=0.89$ ) confirming previous findings. The exclusion of the No-HPD condition from ANOVA did not affect the significance of other factors or factor interactions. Repeated measure ANOVAs on (a) HPD and NOISE and (b) HPD and TEST were also made for NH and HI groups separately. Both analyses showed practically the same effects as the main ANOVAs.

The effects of GENDER, ETHNICITY, and HPD factors were also evaluated in another ANOVA limited to NH subjects and wideband random noise masker but including the TEST factor (test, retest). The results of this analysis confirmed previous findings and indicated that the effect of the TEST factor ( $F=1.03$ ,  $df=1/24$ ,  $p=0.32$ ) was not statistically significant. After exclusion of the No-HPD condition from the analysis, the HPD factor once again had no statistically significant effect on SBG scores.

The mean and standard deviation values of correct responses obtained in the SBG by three ethnic groups of NH subjects are shown in Table 8. The data have been averaged across three noise maskers because the NOISE factor had no statistically significant effect on the SBG scores.

Inspection of Table 8 indicates that Asian Americans differed by 10-15% from non-Asian subjects in the number of correct responses. An average percentage of correct responses for non-Asian subjects wearing either of HPDs was 82.8% whereas for Asian subjects was 68.4%. For comparison, the average score for the group of European HI subjects participating in this study was 68.0%. It is also noteworthy that all three ethnic groups performed similarly on the task when the coordinates were read in quiet and reproduced in noisy environment by the loudspeaker (baseline condition). The numbers of correct responses were 97.0 (SD=4.8), 98.0 (SD=6.3), 96.0 (SD=5.7),

and 94.3 (SD=11.5) for NH African, Asian, and European Americans, and HI European subjects, respectively.

**Table 8.** Mean (M, %) and standard deviation (SD, %) values of correct responses obtained by three ethnic groups of NH subjects in the simulated battleship game (SBG).

Type of Hearing Protection Device	Ethnic Group		
	African Americans	Asian Americans	European Americans
No-HPD M	86.0	73.5	89.5
SD	9.6	13.5	7.2
Ultrafit M	82.3	66.8	84.3
SD	8.1	17.8	11.1
ER-15 M	85.8	69.0	80.8
SD	10.3	18.1	9.6
ER-20 M	82.5	69.3	81.3
SD	7.4	14.1	9.9

Separate repeated measure ANOVAs on NOISE (all three noises) and HPD (No-HPD, Ultrafit, ER-15, ER-20) factors were calculated for each ethnic group of the NH subjects as well as for the whole group of HI subjects. The NOISE factor was not significant in any of these cases. The HPD factor, however, was significant for both groups of European Americans (Group NH:  $F=4.3$ ,  $df=3/27$ ,  $p=0.01$ ; Group HI:  $F=9.07$ ,  $df=3/87$ ,  $p<0.001$ ). In both cases, the elimination of No-HPD condition from analysis made the HPD factor insignificant.

### 11.7. EXPERIMENT 6: SPEECH LEVEL ADJUSTMENT

The Speech Level Adjustment (SLA) data are listed in Table 9. The data are reported separately for the NH and HI subjects, the type of masking noise, and the type of HPD. A mixed design ANOVA on HEARING (Group NH, Group HI) with repeated measures on the TEST (test, retest) and HPD (No-HPD, Ultrafit, ER-15, ER-20) factors for wideband random noise masker showed statistically significant effects of HEARING ( $F=9.22$ ,  $df=1/58$ ,  $p=0.004$ ) and HPD ( $F=26.1$ ,  $df=3/174$ ,  $p<0.001$ ) but not TEST ( $F=0.06$ ,  $df=1/58$ ,  $p=0.81$ ). The interactions among factors were not significant. Post hoc contrast tests revealed that all differences among HPDs and between HPDs and the No-HPD were highly significant ( $p<0.001$  with an exception of ER-15 vs. ER-20 difference that was significant at  $p=0.04$  level). The difference between Ultrafit and ER-20 earplugs was not significant ( $F=1.35$ ,  $df=2/58$ ,  $p=0.27$ ).

Another ANOVA with the added NOISE factor (wideband, industrial, and simulated noise) but limited only to the test data (retest was made for one type of noise

only) showed no statistically significant effect of NOISE ( $F=1.64$ ,  $df=2/116$ ,  $p=0.20$ ) but confirmed the statistical effects of two other main factors - HEARING ( $F=10.08$ ,  $df=1/58$ ,  $p=0.002$ ) and HPD ( $F=23.25$ ,  $df=3/174$ ,  $p<0.001$ ). There were no significant interactions among factors. The contrast analysis on HPD factor showed similar results as the contrast analysis described above.

The gender and ethnic background effects on SLA for normal-hearing listeners were assessed by a mixed design ANOVA on GENDER (male, female) and ETHNICITY (African, Asian, and European Americans) with repeated measures on HPD (No-HPD, Ultrafit, ER-15, ER-20) and NOISE (wideband, industrial, and simulated noise). Results of this analysis showed statistically significant effects of ETHNICITY ( $F=5.28$ ,  $df=2/24$ ,  $p=0.013$ ) and HPD ( $F=19.67$ ,  $df=3/72$ ,  $p<0.001$ ) on SLAs made by NH subjects. Two other main factors, GENDER ( $F=1.31$ ,  $df=1/24$ ,  $p=0.26$ ) and NOISE ( $F=1.47$ ,  $df=2/48$ ,  $p=0.24$ ) and all the factor interactions were not significant. Post-hoc contrast analysis on ETHNICITY demonstrated statistically significant differences between MCLLs for Asian and African Americans ( $F=5.99$ ,  $df=1/18$ ,  $p=0.025$ ) and for Asian and European Americans ( $F=8.36$ ,  $df=1/18$ ,  $p=0.01$ ). The difference between African Americans and European Americans was not significant ( $F=0.82$ ,  $df=1/18$ ,  $p=0.378$ ).

Table 9. Mean (M, dBA) and standard deviation (SD, dBA) values for speech level adjustment (SLA) task performed by NH and HI subjects in various listening conditions.

Type of Hearing Protection Device	Normal-Hearing Listeners				Hearing-Impaired Listeners			
	Industrial Noise	Simulated Industrial Noise	Wideband Noise (test)	Wideband Noise (retest)	Industrial Noise	Simulated Industrial Noise	Wideband Noise (test)	Wideband Noise (retest)
No-HPD M	82.7	82.9	83.0	82.2	88.2	88.0	87.5	87.4
SD	6.0	6.6	6.6	6.3	4.0	4.3	4.3	3.9
Ultrafit M	87.0	87.4	87.2	87.2	90.4	90.9	90.8	90.5
SD	5.1	5.0	6.4	6.4	5.7	5.6	6.2	6.3
ER-15 M	85.5	86.0	85.0	86.4	88.4	88.6	88.6	89.2
SD	5.9	5.6	6.8	5.4	3.9	4.0	4.0	4.4
ER-20 M	86.5	86.7	86.2	86.5	90.1	90.9	90.7	90.0
SD	5.6	5.7	6.4	5.4	5.8	5.0	6.1	5.6

Separate repeated measure ANOVAs on NOISE (WRN, IN, and SIN) and HPD (No-HPD, Ultrafit, ER-15, ER-20) factors were calculated for each ethnic group of the NH subjects as well as for the whole group of HI subjects. The NOISE factor was not significant in any of these cases. The HPD factor, however, was significant for African Americans ( $F=16.03$ ,  $df=3/27$ ,  $p<0.001$ ) and both groups of European Americans (Group NH:  $F=4.81$ ,  $df=3/27$ ,  $p=0.01$ ; Group HI:  $F=8.71$ ,  $df=3/87$ ,  $p<0.001$ ). In all three

cases, eliminating the No-HPD condition from the analysis made the HPD factor insignificant. This result is similar to that reported for the SBG, except for the African Americans.

The mean SLA scores with a breakdown for the ethnic character of the subjects are listed in Table 10. The listed scores have been averaged across both the subjects and the noise maskers.

The data in Table 10 indicate that NH Asian Americans required higher MCLLs for speech in noise than the other subject groups. The average MCLL calculated across all conditions for Asian Americans was 89.3 dBA whereas similar average levels for African Americans and European Americans were 84.6 dBA and 82.7 dBA. For comparison, the grand average of SLAs made by the group of HI subjects, all of them of European descent, was 89.4 dBA. These MCLLs can be easily converted into SNR values for 85 dBA masking noise used in this experiments. For example, the four MCLLs listed above correspond to SNRs of 4.3, -0.4, -2.3, and 4.4 dB, respectively.

Table 10. Mean (M, dBA) and standard deviation (SD, dBA) values for speech level adjustment (SLA) averaged for the three ethnic groups of NH subjects participating in this study).

Type of Hearing Protection Device	Ethnic Group		
	African Americans	Asian Americans	European Americans
No-HPD M	80.9	87.3	80.3
SD	5.1	5.4	5.4
Ultrafit M	87.5	89.9	84.2
SD	3.7	4.7	6.0
ER-15 M	83.7	89.8	83.0
SD	4.0	5.7	5.4
ER-20 M	86.2	89.9	83.3
SD	4.2	4.5	6.6

## 11.8. EXPERIMENT 7: VOCAL EFFORT TEST

Three types of measures were collected from recorded speech samples to determine the effects of various listening conditions on vocal effort. They were: (1) maximum speech level produced during vocalization of the vowel sound in each of the SBG coordinates E-3, O-4, and U-2, (2) average value of the four highest peaks of speech level produced during vocalization of the phrase "Bobo was at the utmost consternation, not so much for the sake of his tenement" (Appendix E), and (3) fundamental frequency of voicing for the word "Bobo" from the previous phrase. The readings were made using Scientific Atlanta SD-380 FFT Analyzer (sound levels) and Kay Elemetrics VisiPitch 6095 (fundamental frequency). The selection of phrase (Bobo

was...his tenement) and word (Bobo) for analysis was made on the basis of several preliminary analyses made on different phrases and words. The selection criteria were (1) clarity of pronunciation and (2) measurement reliability.

Table 11. Vocal Effort Test. Mean (M, dB) and standard deviation (SD, dB) levels of sound pressure produced during vocalization of E-4 coordinate.

Type of Hearing Protection Device	Normal-Hearing Listeners				Hearing-Impaired Listeners			
	Type of noise				Type of noise			
	Industrial Noise	Simulated Industrial Noise	Wideband Noise (test)	Wideband Noise (retest)	Industrial Noise	Simulated Industrial Noise	Wideband Noise (test)	Wideband Noise (retest)
No-HPD M	82.8	83.6	82.7		83.9	83.6	83.3	
SD	5.6	5.9	5.7		4.1	4.8	4.7	
Ultrafit M	78.2	78.6	76.6	78.2	79.8	79.8	78.4	79.6
SD	4.8	4.9	5.6	5.1	3.9	3.8	5.1	4.5
ER-15 M	79.5	79.8	79.1	78.7	80.4	80.2	79.5	80.1
SD	4.4	4.0	3.9	4.7	4.0	5.0	4.7	6.0
ER-20 M	79.0	79.0	78.9	78.4	79.8	79.4	79.0	80.0
SD	4.9	4.3	4.8	5.1	3.3	3.5	3.6	3.9

Table 12. Vocal Effort Test. Mean (M, dB) and standard deviation (SD, dB) levels of sound pressure produced during vocalization of O-4 coordinate.

Type of Hearing Protection Device	Normal-Hearing Listeners				Hearing-Impaired Listeners			
	Type of noise				Type of noise			
	Industrial Noise	Simulated Industrial Noise	Wideband Noise (test)	Wideband Noise (retest)	Industrial Noise	Simulated Industrial Noise	Wideband Noise (test)	Wideband Noise (retest)
No-HPD M	86.4	86.4	86.7		87.3	87.0	86.3	
SD	5.3	5.8	5.7		5.7	5.9	5.6	
Ultrafit M	79.8	80.5	78.6	79.2	81.4	81.4	79.8	80.8
SD	5.6	5.3	5.9	5.1	5.4	5.3	6.3	6.2
ER-15 M	80.6	81.0	80.3	80.5	82.1	82.2	81.6	81.9
SD	5.4	4.3	5.0	5.6	5.5	6.2	6.4	6.0
ER-20 M	80.0	79.8	79.7	79.8	81.0	81.1	80.8	81.0
SD	5.2	5.6	5.3	5.8	4.5	5.2	5.5	5.3

The data obtained in Experiment 7 are listed in Tables 11 through 15. Tables 11 through 14 include speech level data and Table 15 includes fundamental frequency data. Inspection of Tables 11-15 leads to the observation that all speech levels

recorded when the subjects wore HPDs were very similar. Mixed design ANOVA analyses on HEARING (Group NH, Group HI), NOISE (wideband, industrial, and simulated noise), and HPD (No-HPD, Ultrafit, ER-15, ER-20) and on HEARING (Group NH, Group HI), TEST (test, retest), and HPD (No-HPD, Ultrafit, ER-15, ER-20), similar to those described in the previous sections, did not indicate any significant effect of HEARING or NOISE for any of the five indicators listed in Tables 11-15. In all these cases, however, the HPD factor was statistically significant at least at  $p=0.001$  level.

Table 13. Vocal Effort Test. Mean (M, dB) and standard deviation (SD, dB) levels of sound pressure produced during vocalization of U-2 coordinate.

Type of Hearing Protection Device	Normal-Hearing Listeners				Hearing-Impaired Listeners			
	Type of noise				Type of noise			
	Industrial Noise	Simulated Industrial Noise	Wideband Noise (test)	Wideband Noise (retest)	Industrial Noise	Simulated Industrial Noise	Wideband Noise (test)	Wideband Noise (retest)
No-HPD M	82.5	82.4	82.6		83.5	83.4	82.6	
SD	5.0	5.7	5.5		4.9	4.9	5.1	
Ultrafit M	76.2	77.0	75.6	75.9	78.1	78.5	76.2	77.1
SD	5.0	5.2	5.6	5.0	5.2	5.3	6.1	5.9
ER-15 M	77.2	77.7	77.2	76.9	79.0	79.0	78.2	78.4
SD	5.1	4.6	5.0	5.1	5.1	5.3	5.8	5.6
ER-20 M	76.8	76.2	76.4	77.6	78.1	78.0	77.8	78.2
SD	5.0	5.1	5.1	5.2	4.3	4.8	5.3	5.0

Table 14. Vocal Effort Test. Mean (M, dB) and standard deviation (SD, dB) levels of sound pressure produced during vocalization of connected speech.

Type of Hearing Protection Device	Normal-Hearing Listeners				Hearing-Impaired Listeners			
	Type of noise				Type of noise			
	Industrial Noise	Simulated Industrial Noise	Wideband Noise (test)	Wideband Noise (retest)	Industrial Noise	Simulated Industrial Noise	Wideband Noise (test)	Wideband Noise (retest)
No-HPD M	84.5	84.4	84.7		83.6	83.7	84.8	
SD	5.0	4.9	5.2		5.1	4.8	5.1	
Ultrafit M	77.7	78.2	76.8	77.3	79.5	79.0	78.5	78.6
SD	4.9	4.3	5.1	4.8	4.9	5.3	5.3	5.9
ER-15 M	79.0	79.7	79.3	78.9	80.5	80.6	80.1	80.0
SD	4.7	3.5	4.5	5.0	4.8	5.3	5.6	5.7
ER-20 M	78.2	78.5	78.3	77.9	79.6	79.5	80.2	79.5
SD	4.6	4.7	4.5	4.8	3.9	4.4	8.4	5.0

An exclusion of the No-HPD condition from the analysis made the HPD factor not significant for vocalized SBG coordinates and the fundamental frequency in "Bobo". However, the HPD factor still had a significant effect on the level of production of connected speech ( $F=6.86$ ,  $df=2/108$ ,  $p=0.003$ ). Post-hoc contrast analysis revealed that all the differences between HPD conditions were statistically significant ( $P<0.01$ ) except for the ER-15 and ER-20 pair ( $F=0.99$ ,  $df=2/54$ ,  $p=0.379$ ).

The data listed in Tables 11-14 indicate that the level of connected speech was affected by the type of HPD whereas the isolated speech sounds were affected by wearing HPDs but not by the type of HPDs. The level differences between No-HPD and all HPD conditions were in order of 3 to 5 dB. These values agree well with data reported earlier by Howell and Martin (1975). All factor interactions calculated in this part of data analysis were not significant.

Table 15. Vocal Effort Test. Mean (M, Hz) and standard deviation (SD, Hz) values of fundamental frequency during vocalization of word "Bobo".

Type of Hearing Protection Device	Normal-Hearing Listeners				Hearing-Impaired Listeners			
	Industrial Noise	Simulated Industrial Noise	Wideband Noise (test)	Wideband Noise (retest)	Industrial Noise	Simulated Industrial Noise	Wideband Noise (test)	Wideband Noise (retest)
No-HPD M	277	271	287		245	243	246	
SD	63	71	74		71	70	78	
Ultrafit M	231	239	227	233	206	209	205	208
SD	66	65	66	64	68	70	68	69
ER-15 M	239	236	238	236	216	211	214	207
SD	62	60	64	71	68	67	73	68
ER-20 M	234	235	239	232	208	213	207	212
SD	67	67	69	61	72	72	67	71

The data analysis limited to the group of NH subjects showed no statistically significant effect of ETHNICITY (African, Asian, and European Americans), TEST (test, retest), or NOISE (wideband, industrial, and simulated noise). The HPD factor (No-HPD, Ultrafit, ER-15, ER-20) was highly significant for both the speech levels ( $p<0.001$ ) and the fundamental frequency ( $P<0.03$ ). The exclusion of No-HPD condition from the analysis made the HPD factor not significant for SBG coordinates and fundamental frequency of "Bobo". The HPD factor, however, remained still significant in the case of the level of connected speech. This is true for productions made by NH as well as HI subjects. The only difference between both groups was that the productions of E-3 coordinate by HI subjects were not affected at all by the HPD factor. This may be caused by a poor audibility of the "E" sound, which has mostly high frequency content.

The GENDER factor (male, female) was not significant for all speech level measures but was significant for fundamental frequency in "Bobo" ( $F=29.76$ ,  $df=1/20$ ,

$p < 0.001$ ). This effect was to be expected due to the natural difference in fundamental frequency of female and male voices. The average fundamental frequencies in vocalizing the word "Bobo" by male subjects were about 210 Hz and 175 Hz for productions without and with HPDs, respectively. The fundamental frequencies in the same vocal productions made by female subjects were in order of 295 Hz and 330 Hz, respectively.

It is well known that noise causes an upward shift in the fundamental frequency of voice. For example, Letowski, Frank, and Caravella (1993) reported upwards shifts in fundamental frequencies of vocal productions of female and male talkers in order of 20 Hz to 30 Hz due to the presence of a 90 dB SPL background noise. The present study indicates that wearing HPDs reduces this shift. However, no statistically significant interactions of GENDER and HPD and GENDER and NOISE were found.

## 12. GENERAL DISCUSSION

### 12.1. HEARING PROTECTOR ATTENUATION

Three HPDs compared in this study differed in their attenuation functions measured with REAT procedure and in their overall sound pressure attenuation measured by SPARE method. The actual SPARE values were about 10, 13, and 12 dB for Ultrafit, ER-15, and ER-20 earplugs, respectively.

The REAT frequency response functions of the HPDs are shown in Table 3. The data for ER-15 earplug are almost identical for both groups of subjects. The greatest difference in the data obtained with both groups of subjects is a 3 dB parallel shift toward greater attenuation in REAT values for the ER-20 earplugs obtained with HI subjects. Overall, however, there is a good agreement between the data from both groups of subjects. This agreement indicates that people with marginal and mild hearing loss could participate in REAT testing without affecting the data beyond reasonable limits.

The data for the ER-15 and ER-20 HPD agree quite well ( $\pm 2$  dB) with the manufacturer's data, with the exception of 500 and 1000 Hz where differences up to 5 dB were observed. However, data for the Ultrafit earplug are on average 10 to 15 dB lower than the data published by the manufacturer. In addition, the NRR values for all earplugs are irrationally low (-2 to 0 dB). The authors argue that both the attenuation data for Ultrafit earplug and low NRR values were due to the fitting procedure used in this study.

The informed-subject fit is a non-ideal fit that should approximate realistic earplug insertion by experienced user. Such non-ideal fitting strategy did not affect much ER-15 and ER-20 earplugs, both of which have some controlled leakage. However, a non-ideal fitting strategy of the high-attenuation Ultrafit earplugs affected substantially noise attenuation capability of the earplug. These earplugs are intended to provide a good seal of the ear canal and lose their high-attenuation properties if such a seal is not obtained.

## 12.2. TEST-RETEST RELIABILITY

Test reliability was assessed in all experiments but REAT and SPARE experiments (see Section 10.9). The subjects' reliability was measured by test-retest comparison for all four HPD worn in the wideband random noise masker condition. In all investigated tasks there was no statistically significant difference between test and retest results. This finding indicates good reliability of the data obtained in both perceptual and vocal tasks investigated in the study.

## 12.3. EFFECTS OF HEARING PROTECTION

Hearing protection significantly affected all speech-related tasks investigated in the study except for the WRS and SIR tasks. In the simulated Battleship game scenario, the number of correctly recognized SBG coordinates dropped by 3% to 12% after insertion of HPD earplugs in the subject's ears. For the same conditions, most comfortable listening level (MCLL) for speech in noise in NH subjects increased approximately by 4 dB. This shift corresponds to the change in the preferred SNR from -2 dB to +2 dB. Smaller shifts, by approximately 2 dB, were observed in the case of HI subjects. In this case, the preferred SNR increased from +3 to +5 dB.

Wearing HPDs affected also speech production in noise. The speech levels produced in Experiment 7: Vocal Effort Test were about 4 to 6 dB lower for talkers with HPDs than for talkers without HPDs. The size of this effect was practically the same in the case of connected speech as in the case of Battleship game coordinates. Similar level changes have been reported earlier by Howell and Martin (1975) and Hoermann et al., (1984) for monosyllabic words.

Hearing protection does not only affect the level of speech. In the VET experiment the fundamental frequency of a vowel "o" spoken in "Bobo" was approximately 30 Hz higher in productions made with HPDs than in productions made without HPDs. There were also noticeable differences on speech quality. All talkers tended to speak slower and more distinctly with than without HPDs. Similar changes in fundamental frequency and speech quality were also reported by Howell and Martin (1975) and Letowski, Caravella, and Frank (1993).

Overall, the observed effects of hearing protection on speech communication were largely negative. Hearing protection decreased efficiency of speech communication in noise when both the talker and the listener were wearing HPDs. This effect may be partially due to lower natural speech levels produced by talkers wearing HPDs (see also Howell and Martin, 1975). Subjects wearing HPDs also required higher speech levels and better SNRs for comfortable communication.

Results of this study support general conclusions reached by Coles and Rice (1966), Bauman and Marston (1986), and Johnson and Wise (1992) that hearing protection negatively affects speech recognition in noise. Reports indicating improvement in speech communication (see: Kryter, 1947, Michael, 1965; Williams, Forstall, and Parsons, 1971; Lindeman, 1976, Berger, 1982; Pekkarinen et al., 1990ab) were not confirmed.

## 12.4 EFFECTS OF HEARING PROTECTOR TYPE

Speech communication data were not affected by the type of HPD except for the MCLLs measured in the SLA experiment and the connected speech production level measured in the VET experiment. In both cases, differences between the Ultrafit earplug and the two other earplugs were statistically significant at 0.04 or better level. Although significant, these differences were relatively small (1-2 dB) and as such may not be practically important. Differences between ER-15 and ER-20 HPDs were not significant.

It is the authors opinion that, in the case of informed-user fit, the results of the study do not demonstrate any practical advantage of the ER-15 and ER-20 earplugs over Ultrafit earplug for speech communication. It has to be stressed again, however, that the attenuation data for Ultrafit earplugs differ very much from the published data unlike in the case of the two other earplugs. The authors hypothesized that this effect was due to the fitting procedure used in this study.

## 12.5. EFFECTS OF NOISE

Temporal and spectral differences among the three noise types used in this study did not affect the results of any of the experiments. This simply indicates that the differences among the noises were too small to noticeably affect speech perception or effective noise attenuation. It is very likely, as it has been indicated by other studies, that sufficiently large changes in noise properties would affect the results of this study. However, obtained results indicate that the simulation of typical industrial noises with spectrally equalized random noise does not noticeably affect perception and can be considered an acceptable practice in predicting the effects of noise on people. It seems also that random wideband noise can be successfully used as a masker in predicting gross human behavior in noisy industrial environments.

## 12.6. EFFECTS OF HEARING IMPAIRMENT

Hearing impairment did not significantly affect either the REAT and SPARE data. The REAT values for the ER-15, ER-20, and Ultrafit earplugs were very similar for NH and HI subjects with a tendency for HI subjects to receive slightly more attenuation. Similar tendencies were reported earlier by Berger (1985) for earplugs and Suter, Lempert, and Franks (1990) for earmuffs. In addition, hearing impairment had no effect on either the WRS and SIR scores or the VET data. These findings indicate that (1) marginal-to-mild or even moderate sensorineural hearing loss may be acceptable in selecting human listeners for HPD evaluation, (2) WRS and SIR tasks lack sufficient sensitivity to be used as reliable and valid audiological tests for mild-to-moderate sensorineural hearing losses, and (3) vocal production is not noticeably affected by mild-to-moderate sensorineural hearing loss. However, the effects of hearing

impairment were observed in both the SBG and SLA tasks. These effects can be summarized as follows:

1. hearing loss significantly affected communication in noise (decrease by 10%) both with and without HPDs as measured by SBG task; it did not affect, however, performance in SBG task when coordinates were spoken in quiet by the experimenter (trained voice) and reproduced in noisy environment through the loudspeaker (baseline condition) and
2. hearing loss significantly affected the selection of MCLL for speech in noise both with HPDs (MCLL increased by 3 dB) and without HPDs (MCLL increased by 5 dB).

Overall, the results of this study support a general notion that hearing impairment negatively affects speech communication in noise. This result was to be expected (see: Tillman, Carhart, and Olsen, 1970). Previous studies indicated also the presence of an interaction between hearing impairment level and hearing protection type affecting speech communication (see: Chung and Gannon, 1976; Rink, 1979; Bauman and Marsten, 1986). However, the HPDs used in those studies were high-attenuation earmuffs. Low-attenuation HPDs used in the present study did not reveal that interaction. This indicates that people with small degree of hearing loss may communicate in noise as well as normally hearing people when both groups use low-attenuation HPDs.

## 12.7. EFFECTS OF GENDER

The gender effects were not observed in any of the experimental tasks but the VET. Fundamental frequency of vowel "o" production in "Bobo" was statistically different for male and female talkers. This effect, however, was to be expected due to the natural difference in fundamental frequencies of female and male voices. In addition, there were no significant interactions of GENDER with any other factors in respect to fundamental frequency. Moreover, the GENDER factor did not affect the vocal levels.

## 12.8. EFFECTS OF ETHNICITY

The effects of ethnicity were observed in both the SLA task and the SBG task related to speech produced in noise. In both cases Asian Americans significantly differed from African and European Americans. However, no effects were observed in the case of the SBG task related to speech produced in quiet and reproduced in noise. The ethnicity factor was not statistically significant in any other task investigated in this study.

The cause of the differences in performance between Asian American and African and European American subjects on SLA and SBG tasks remains unclear. These differences do not seem to be related to anthropological differences in the ear canal or the quality of earplug insertion since Asian Americans performed poorer than African Americans and European Americans both with and without HPDs. In addition, the ER-20 earplugs were individually customized for each subject. It may be just that observed differences were incidental and related to small sample size. It may also be, however, that comfort, performance, and ability to understand speech by people of Asian descent are affected more by high noise levels than those of people of African or European descent. This hypothesis is supported by informal comments made by the subjects of Asian descent who felt less comfortable in attempting to communicate in noise than two other groups of subjects. Asian Americans seem to be more focused and less distracted at home, prefer quiet types of recreational activities, and consider the presence of noise at the work place as an important negative factor.

### 13. CONCLUSIONS

Results obtained in the set of seven experiments conducted in this study seem to be quite consistent and straightforward. They can be summarized by the following general conclusions and comments. Additional information is provided in the DISCUSSION section of this report.

1. Speech communication investigated within the constraints of this study was affected negatively by the use of hearing protectors, especially by the talker. Simulated Battleship Game (SBG) and Speech Level Adjustment (SLA) tasks seem to be especially useful in assessing human communication in noise both with and without HPDs.
2. Speech communication with HPDs is affected negatively by lower speech levels of the talkers and higher preferred SNR by the listeners in comparison to speech communication without HPDs.
3. Speech communication with flat-attenuation hearing protectors ER-15 and ER-20 did not differ noticeably from that with Ultrafit earplugs when the earplugs were inserted using the informed-user fitting strategy.
4. The informed-user fitting strategy, which is based on the initial verbal training of the user without constant monitoring of the quality of earplug insertion, did not significantly affect the amount of attenuation offered by the HPDs with controlled acoustic leakage but affected greatly the amount of attenuation offered by the earplugs intended for a tight ear seal.
5. Marginal-to-moderate sensorineural hearing loss did not significantly affect speech communication with hearing protectors. In

addition, small amounts of sensorineural hearing loss do not seem critical in selecting subjects for REAT testing of HPDs.

6. Word recognition score (WRS) and speech intelligibility rating (SIR) tests are not sensitive enough to be used for assessing of speech perception in noise both with and without HPDs.
7. Ethnic backgrounds and related cultural differences may affect, under some conditions, speech communication in noise both without and with HPDs.
8. Small spectral and temporal differences in the masking noises investigated in this study, did not significantly affect speech communication in noise.
9. Results of this study indicate that the SBG task may be developed in a practical test for the assessment of speech communication in various acoustic conditions. However, further research directed toward obtaining normative data and sensitivity measures is needed.
10. Further investigations of the effects of flat- and non-flat-attenuation HPDs on speech perception in vastly different industrial noises is needed to determine optimal combinations of background noise and HPD for effective speech communication.

#### 14. ACKNOWLEDGMENTS

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## 16. LIST OF PLANNED PUBLICATIONS

- Letowski T et al. Effect of hearing impairment on Real Ear Attenuation at Threshold data (in preparation).
- Letowski T et al. Speech communication with and without hearing protection devices (in preparation).
- Letowski T et al. Effect of hearing protection on speech production in noise (in preparation).

## 17. FINAL INVENTION STATEMENT

The Simulated Battleship Game strategy seems to be appropriate for assessing of speech communication in various adverse acoustic conditions. Further research is needed to develop a formal test procedure, to gather normative data, and to determine test sensitivity.

## 18. APPENDICES

### 18.1. APPENDIX A

#### EXPLANATION OF THE STUDY

Title: Speech Communication with Flat Attenuation Hearing Protectors

Principal Investigator: Tomasz R. Letowski

The purpose of this study is to compare speech communication and noise attenuation measures of flat-attenuation hearing protection devices (HPDs) in industrial noisy environments. All HPDs used in this study will have a form of an earplug. You are asked to participate in seven different experiments in which you will perform various activities while exposed to noise with or without earplugs. During all experiments you will be seated and completing your tasks in a sound-treated test room providing comfortable listening conditions. You will be required to participate in several listening sessions lasting approximately 12 hours overall. In each experiment three types of HPDs will be evaluated in the presence of three types of background noise. You will be also required to listen to each of the noise without HPDs. Under no circumstances the noise levels used in this study will be harmful and in any other way detrimental to your health.

In **Experiment 1: Real Ear Attenuation at Threshold** you will be asked to respond to different narrow-band noises. You will respond by pressing a response button every time you hear the noise and releasing it when the noise is not audible. You repeat the same test without and with earplugs. This is being done to determine the amount of noise that is reduced when you wear an earplug. In **Experiment 2: Sound Pressure Attenuation in Real Ear** a small probe microphone will be inserted into your ear canal occluded or not occluded with an earplug. Your task is simply to sit in the test room while the experimenter records sound pressure level of noise in your ear canal. Your task in **Experiment 3: Word Recognition Test** is to write down on an answer sheet the target words presented in noise. Again, you will listen to the speech signal without and with earplugs. In **Experiment 4: Speech Intelligibility Rating** you will listen to a taped story and judge perceived speech intelligibility on a scale from 0 to 100%. This experiment is very similar to Experiment 3. Your task in **Experiment 5: Simulated Battleship Game** is to write down coordinate cues given you by another person and to read coordinate cues to the other person. In **Experiment 6: Speech Level Adjustment** you will be asked to adjust speech signal to most comfortable listening level while listening to speech in noise without and with earplugs. Finally, in **Experiment 7: Vocal Effort Test** a laryngeal microphone will be strapped to your neck and you will be asked to record your voice while reading aloud in quiet and in noise.

You should not feel any discomfort during any part of the study. In the unlikely event that you experience any pain or discomfort during participation in the study, you should immediately interrupt the test and indicate the presence of discomforting condition to the experimenter.

The results of this study are expected to determine environmental conditions that are appropriate for wearing flat-attenuation HPDs in industrial settings. Collected data will also be used to assess efficacy of various speech communication measures for assessment of HPD effectiveness.

\_\_\_\_\_  
Date

\_\_\_\_\_  
Subject's Signature

\_\_\_\_\_  
Witness Signature

18.2: APPENDIX B

**INFORMED CONSENT FORM**

Title: Speech Communication with Flat Attenuation Hearing Protectors

Principal Investigator: Tomasz R. Letowski

This is to certify that I, \_\_\_\_\_, hereby agree to participate as a volunteer in a scientific investigation carried out at The Pennsylvania State University under the supervision of Tomasz R. Letowski, Ph.D.

The investigation and my part in it have been defined and fully explained to me by Tomasz R. Letowski, Ph.D. or Nancy Poch, M.S. and I understood the explanation. A copy of the explanation of this study has been provided for and a description of any risk and discomforts have been discussed in detail with me. I have been given the opportunity to ask whatever questions I may have had and all such questions and inquiries have been answered to my satisfaction.

I understand that any data will remain confidential with regard to my identity. I also understand that, in unlikely event of physical injury resulting from this investigation, neither financial compensation nor free medical treatment is provided for such a physical injury, and that further information on this policy is available from the Senior Vice President for Research and Dean of the Graduate School, 114 Kern Building, University Park, PA, telephone 1-814-865-6331.

I certify that to the best of my knowledge and belief, I have no physical or mental illness or weakness that would increase the risk to me of participation in this investigation.

**I FURTHER UNDERSTAND THAT I AM FREE TO WITHDRAW MY CONSENT AND TERMINATE MY PARTICIPATION IN THE DESCRIBED STUDY AT ANY TIME.**

\_\_\_\_\_  
Date

\_\_\_\_\_  
Subject's Signature

\_\_\_\_\_  
Date

\_\_\_\_\_  
Experimenter's Signature

18.3. APPENDIX C

**CASE HISTORY FORM**

Name: \_\_\_\_\_ DOB: \_\_\_\_ - \_\_\_\_ - \_\_\_\_ Age: \_\_\_\_\_

Street: \_\_\_\_\_ City: \_\_\_\_\_ State: \_\_\_\_\_

Phone \*: (\_\_\_\_) \_\_\_\_\_ S.S. # \_\_\_\_ - \_\_\_\_ - \_\_\_\_\_

1. Do you have any hearing difficulties? Yes No

If so, how long? \_\_\_\_\_

2. Is there any history of hearing loss in your family? Yes No

If yes: When \_\_\_\_\_  
Treatment \_\_\_\_\_

3. Do you have any ringing in your ears? Yes No

If yes: Right ear only Left ear only Both ears

4. Have you had surgery for your ear, nose or throat? Yes No

If yes, explain: \_\_\_\_\_

6. Have you had any recent head injuries, high fevers or serious illnesses? Yes No

If yes, explain: \_\_\_\_\_

7. Have you worked in an environment where hearing protection was required? Yes No

If yes, did you use hearing protection devices? Yes No

-----For Clinical Use Only-----

RE	RE	LE	LE	SRT:	RE	LE
250 _____	_____	250 _____	_____	WRS:	RE _____	@ 40 dB SL re: SRT
500 _____	_____	500 _____	_____	WRS:	LE _____	@ 40 dB SL re: SRT
1000 _____	_____	1000 _____	_____			
2000 _____	_____	2000 _____	_____			
3000 _____	_____	3000 _____	_____			
4000 _____	_____	4000 _____	_____	AR:	1K	2K
6000 _____	_____	6000 _____	_____		_____	_____ Present
8000 _____	_____	8000 _____	_____		_____	_____ Absent

## 18.4. APPENDIX D

**INSTRUCTIONS****EXPERIMENT 1: REAL EAR ATTENUATION AT THRESHOLD**

## Instructions

You will be seated in the center of a room equipped with several loudspeakers. Do not pay attention to any particular loudspeaker and listen for the presence of various narrow-band noises. They will differ both in pitch, that is, in perceived frequency, and in loudness. You will be listening alternatively without and with hearing protection devices (HPDs). Each time you are fitting the HPDs for the test, you will hear a wide-band noise ("static") that will help you to know when you have the best fit. The HPDs should eliminate as much of this noise as possible. When you are ready, give a signal to the experimenter that you are ready to begin the test. The wideband noise will be turned off and the test signal will begin.

The test signal will be a pulsating narrow-band noise. When you hear the noise, press the response button and hold it in. The signal will get softer. When you no longer hear the noise, let go of the response button. The signal will start to get louder again. When you hear the noise again, press the response button. Continue this until the test ends. There will be four different listening conditions in this test, and each condition will be repeated three times. You will be told each time when and which HPDs should be used.

Remember, that in the very unlikely event that the sound becomes very uncomfortable or painful close your ears with your hands. This will signal the examiner to discontinue the experiment immediately. If you have any further questions, please ask. Thank you for your participation in this study.

**EXPERIMENT 2: SOUND ATTENUATION IN THE EAR CANAL**

## Instructions

You will be seated in the center of a room equipped with several loudspeakers and listening to wide-band noise. The experimenter will measure sound pressure levels in your ear canal without and with hearing protection device (HPD). Your task will be to sit still and allow the experimenter to insert or remove HPDs together with the probe microphone tube according to the test protocol. This is the only part of the study in which you will not insert HPDs yourself.

Remember, that in the very unlikely event that the sound becomes very uncomfortable or painful, interrupt the test immediately and let the experimenter know about

your discomfort. If you have any further questions, please ask. Thank you for your participation in this study.

### **EXPERIMENT 3: WORD RECOGNITION TEST**

#### **Instructions**

You will be sitting in the center of a room, facing a loudspeaker. The test signals will be lists of various words presented through the loudspeaker. You will be asked to listen to individual words and write them down. The words will be presented in a background of three different types of noise. In addition, there will be four different listening conditions in this test:

1. no hearing protection
2. hearing protection with E.A.R. Ultrafit Earplugs (YELLOW)
3. hearing protection with ER-20 Earplugs (WHITE)
4. hearing protection with ER-15 Musician's Earplugs (CUSTOMIZED).

Each list will consist of 50 phrases, "Say the word \_\_\_". Please write down the target word at the end of each phrase. Ignore the noise and take a guess if you are not sure of the word. Please concentrate because you will have only a few seconds to answer after each word.

Remember, that in the very unlikely event that the sound becomes very uncomfortable or painful, interrupt the test immediately and let the experimenter know about your discomfort. If you have any further questions, please ask. Thank you for your participation in this study.

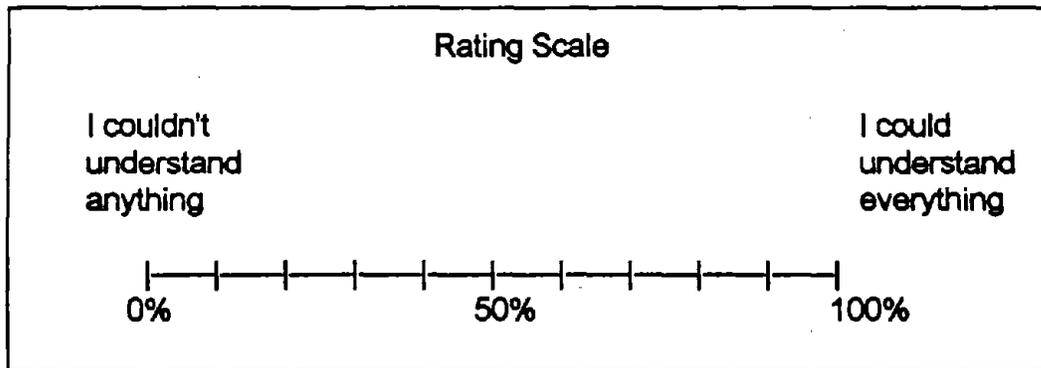
### **EXPERIMENT 4: SPEECH INTELLIGIBILITY RATING**

#### **Instructions**

You will be sitting in the center of a room, facing a loudspeaker. The test signal will be a long passage read by a female talker and presented through the loudspeaker. You will be asked to listen to this passage for about a minute and then judge how much of the text you heard clearly. The passage will be presented in a background of three different types of noise. In addition, there will be four different listening conditions in this test:

1. no hearing protection
2. hearing protection with E.A.R. Ultrafit Earplugs (YELLOW)
3. hearing protection with ER-20 Earplugs (WHITE)
4. hearing protection with ER-15 Musician's Earplugs (CUSTOMIZED).

Each time after the passage ends and the noise is turned off you will be asked to judge the clarity of the speech on a 0% to 100% scale (0% = I couldn't understand anything, 100% = I could understand everything). Put an X along the point on the line at the bottom of the page that corresponds with the amount of the text that you understood.



Remember, that in the very unlikely event that the sound becomes very uncomfortable or painful, interrupt the test immediately and let the experimenter know about your discomfort. If you have any further questions, please ask. Thank you for your participation in this study.

## **EXPERIMENT 5: SIMULATED BATTLESHIP GAME**

### **Instructions**

You will be sitting in the center of a room, facing your partner. There will be a piece of fabric placed between both of you in order to eliminate transmission of visual cues between your partner and you. You will each listen to sets of coordinates, such as A7, C5, and so on. You will hear the coordinates in a background of three different types of noise. In addition, there will be four different listening conditions in this test:

1. no hearing protection
2. hearing protection with E.A.R. Ultrafit Earplugs (YELLOW)
3. hearing protection with ER-20 Earplugs (WHITE)
4. hearing protection with ER-15 Musician's Earplugs (CUSTOMIZED).

The actual test will consist of two parts:

**PART 1.** The examiner will read to you a set of ten coordinates, such as A1, D8, or I1, which you will hear through a loudspeaker. Please write each coordinate as you hear it on the response sheet.

**PART 2.** In this part of the test you and your partner will alternate in calling out coordinates to each other. This is meant to be similar to the way you would call out the coordinates in the Battleship Game. Each of you will read 20 coordinates from the list provided by the examiner. The examiner will ask one of you to begin. You will then take turns calling out coordinates with your partner. Write down each coordinate as you hear it in the blank spaces provided on your list. Continue with this process until all the words in your list have been read aloud. Try to speak up so your partner can hear the coordinates despite the presence of the loud background noise around you.

Remember, that in the very unlikely event that the sound becomes very uncomfortable or painful, interrupt the test immediately and let the experimenter know about your discomfort. If you have any further questions, please ask. Thank you for your participation

### SPECIFIC DIRECTIONS

On the left of your page is the list of coordinates you will use to call out to your partner. On the blank lines in the right column, please write each coordinate as it is called out by your partner. Remember that you will be taking turns. You will call out a coordinate and your partner will write it down. When he finishes writing, he will call out the next coordinate and you will write it down.

## **EXPERIMENT 6: SPEECH LEVEL ADJUSTMENT**

### Instructions

You will be sitting in the center of a room, facing a loudspeaker. The test signal will be a long passage read by a female talker and presented through the loudspeaker. The speech will be initially presented at a low loudness level. As you listen to the speech, the examiner will raise its loudness level. The purpose of this test is to present the speech signal to you at your most comfortable listening level. Raise the index finger of your left hand and hold it up as long as you want the examiner to increase the loudness of the speech. If it becomes too loud, point your finger downward. Continue this procedure of signaling the examiner to increase and decrease the loudness until you are satisfied with the level of the sound. When the loudness of the speech is satisfactory to you, indicate this to the examiner by holding your hand parallel to the floor.

The passage will be presented in a background of three different types of noise. In addition, there will be four different listening conditions in this test:

1. no hearing protection
2. hearing protection with E.A.R. Ultrafit Earplugs (YELLOW)
3. hearing protection with ER-20 Earplugs (WHITE)
4. hearing protection with ER-15 Musician's Earplugs (CUSTOMIZED).

Remember, that in the very unlikely event that the sound becomes very uncomfortable or painful, interrupt the test immediately and let the experimenter know about your discomfort. If you have any further questions, please ask. Thank you for your participation in this study.

## **EXPERIMENT 7: VOCAL EFFORT TEST**

### **Instructions**

You will be given a section of a story (The Dissertation on the Roast Pig) to read aloud. Please read at a loudness level that allows you to hear yourself speak. Three different types of noise (industrial noise, simulated industrial noise, and white noise) will be presented over the loudspeakers during your reading. You will be asked to read the story under four different conditions:

1. using no hearing protection
2. using the E.A.R. Ultrafit Earplugs (YELLOW)
3. using the ER-20 Hi-Fi Earplugs (WHITE)
4. using the ER-15 Musician's Earplugs (CUSTOMIZED)

Remember, that in the very unlikely event that the sound becomes very uncomfortable or painful, interrupt the test immediately and let the experimenter know about your discomfort. If you have any further questions, please ask. Thank you for your participation in this study.

### **SPECIFIC DIRECTIONS:**

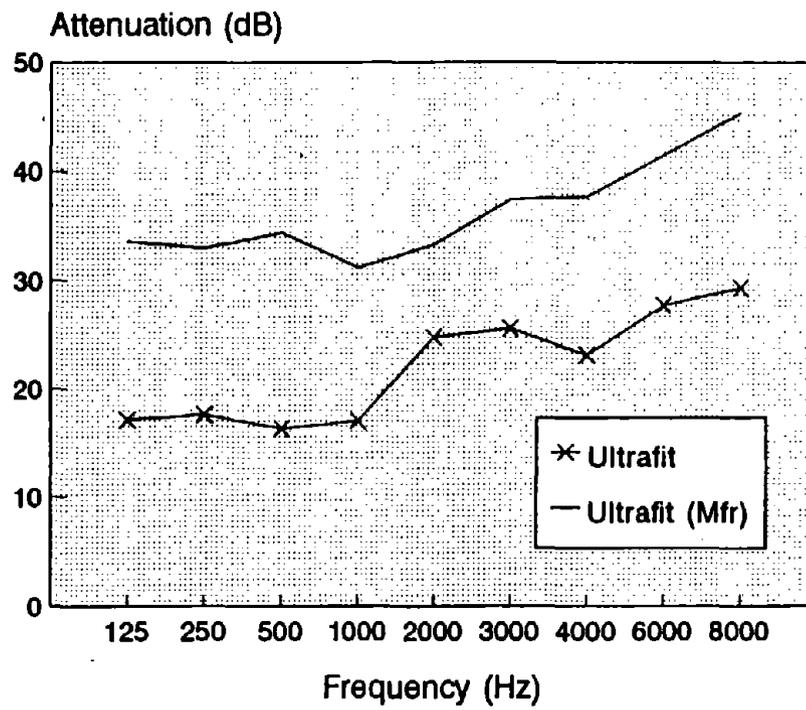
When indicated by the experimenter, begin to read the story aloud from the beginning. Continue reading until the experimenter indicates that you may stop. Then read aloud the three sets of coordinates written at the top of the page in front of you. If you are unsure of how to pronounce a word, take a guess. Read loud enough so that you can hear yourself talk. Please try to remain at the same loudness level throughout each test condition. This procedure will be repeated several times. The researcher will inform you when to begin reading and stop reading during each test condition. At the end of each passage you will also be asked to call out three sets of coordinates similar to those used in the Simulated Battleship Game.

## 18.5. APPENDIX E

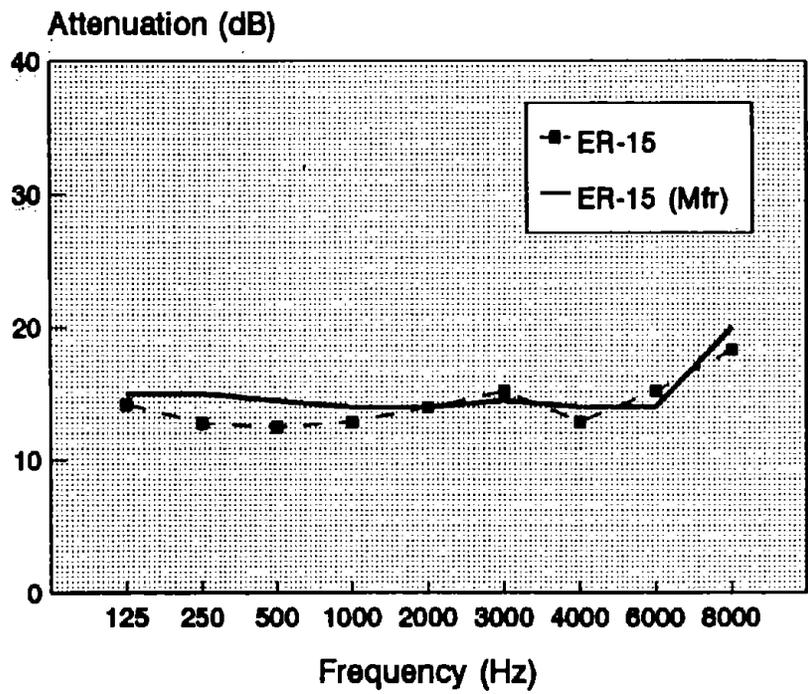
## DISSERTATION ON THE ROAST PIG

(excerpt)

The swine herd Hoti, having gone out into the woods one morning to collect mast for his hogs, left his cottage in the care of his eldest son Bobo. A great lubberly boy who, being fond of playing with matches as yonkers his age commonly are, let some sparks escape into a bundle of straw, which kindling quickly, spread the conflagration over every part of their poor mansion till it was reduced to ashes. Together with the cottage, what was of much more importance, a fine litter of new farrowed pigs, no less than nine in number perished. China pigs have been esteemed a luxury all over the east from the remotest period that we read of. Bobo was in the utmost consternation, not so much for the sake of his tenement, which his father and he could easily build up again with a few dried branches and the labor of an hour or two at any time, as for as the loss of the pigs. While he was thinking what he should say to his father and ringing his hands over the remnants of one of those untimely sufferers, an odor assailed his nostrils unlike any scent he had before experienced. What could it proceed from? Not from the burnt cottage. He had smelled that smell before. Indeed this was by no means the first accident of the kind, which had occurred through the negligence of this unlucky young firebrand. Much less did it resemble that of any known herb, weed or flower. A predominant moistening at the same time overflowed his nether lip. He knew not what to think. He next stooped down to feel the pig to see if there were any signs of life in it. He burnt his fingers and to cool them in his booby fashion he raised them to his mouth. Some of the crumbs of the scorched skin had come away with his fingers and for the first time in his life, he tasted crackling. Again he felt and fumbled at the pig. It did not burn him so much now. Still he licked his fingers from a sort of habit. The truth, at length, broke into his slow understanding that it was the pig that smelled so and the pig the tasted so delicious, and surrendering himself up to the newborn pleasure, he fell to tearing up whole handfuls of the scorched skin with the flesh next to it and was cramming it down his throat in his beastly fashion when his sire entered amid the smoking rafters armed with a retributory coddle and finding how affairs stood began to reign blows upon the young rogue's shoulders as thick as hail stones, which Bobo heeded no more than if they had been flies. The tickling pleasure which he felt in his lower regions had rendered him quite callous to any inconveniences he might feel in those remote quarters. His father might lay on , but he could not beat him from his pig till he had fairly made an end of it and, becoming a little more sensitive of his situation, something like the following dialogue ensued: You graceless whelp!



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